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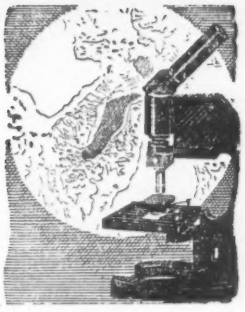

The Corrosion Resistance of Wrought Iron

By J. P. Chilton and U. R. Evans

SYNOPSIS

The corrosion of wrought iron differs from that of typical steel by its zonal character; a superior resistance is obtained in wrought iron only if the geometrical arrangement is such as to take advantage of the zonal character. The *Q* (quickly corroding) and *R* (resistant) zones present even in unpiled wrought iron differ in the 'accessibility' of the sulphide present; especially in corrosion by acids, the liberation of hydrogen sulphide in the *Q* zones stimulates the anodic reaction, so that they are attacked more quickly than the *R* zones, producing the characteristic wooden appearance. When the acid already contains hydrogen sulphide, the attack on the *R* zones also is stimulated and the corrosion becomes more uniform. The *V* (very resistant) zones are only present in piled iron, and represent internal layers of a noble alloy, due to selective oxidation of the surfaces of the pieces composing the pile, with consequent enrichment in copper and nickel. The question of whether *V* zones could be formed by piling steel under suitably modified conditions might be worth investigating. 1069

DISAGREEMENT still exists about whether, for practical purposes, wrought iron resists corrosion better than steel. Numerous observations have been made of iron objects and structures which have given quite extraordinary service, particularly when compared with similar steel objects. Cases of longevity have been reported in many different media, including (*a*) rural, industrial, and marine atmospheres, (*b*) fresh and sea waters, and (*c*) underground situations.

However, these observations are qualitative. All reliable measurements suggest that the difference in corrosion velocity of iron and steel is small. This applies even to the iron made over 100 years ago. Mallett[1] in 1838 stated that wrought iron was not appreciably superior to a steel made by a cementation process. Hudson,[2] in his extensive tests in many different environments, estimated the superiority of iron over copper-free mild steel at about 30%, and found that the superiority over a copper-bearing steel was negligible. Indeed, not a single controlled field or laboratory test yet carried out has shown wrought iron to possess a phenomenally good resistance to corrosion. Thus we are faced with an anomaly in that observation on large structures suggests that wrought iron may sometimes give quite exceptional service, whilst controlled measurements on small specimens point to the opposite conclusion. It is very possible that the remarkable longevity of some iron may be due not to a low velocity of corrosion but to a low probability.

Three occasional causes of faulty judgment must be borne in mind. The first is the tendency to rate the products of the past higher than those of the present. This may sometimes be due to the fact that a representative sample of present products is available to the person forming the judgment, whereas his sample of past products is not representative, since the worst ones will already have perished. Thus the survivors are better than the true average of past products, and if materials have in truth neither improved nor declined in quality, the old ones are likely to be judged better than the new. Whether this be the reason or no, the complaint that 'iron is not as good as it used to be' has been heard for 1900 years. Pliny[3] tells how an iron bridge, built across the Euphrates by Alexander the Great, received some replacements or additions in Pliny's own time; the new material was soon rusting, whilst the old Macedonian iron was still in good condition.

A second factor is the tendency to attribute to the material what is really due to the environment, and the third is the belief that a material is resistant when in fact it has been kept well covered during its lifetime by some protective coating.

Ancient iron objects in Eastern countries remain in good condition, but portions of these objects, if cut off and placed in rather more corrosive atmospheres

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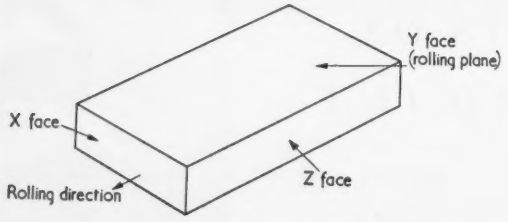


Fig. 1—Identification of the different faces of an iron block

(such as obtain in Europe), have rapidly been attacked.[4, 5] It is understood[6] that specimens of steel exposed near the Delhi Pillar, which has remained unrusted for 1600 years, rusted extremely slowly compared to similar specimens in an English country town.

Certain wrought-iron objects and structures have remained unrusted in British environments during long periods, but it is not always certain whether they received protection during the early part of their lives. Even if it were known that there had been no protection, it would still be uncertain how far longevity was due to the material and how far to a favourable environment in the early stages of exposure. It is often the initial conditions of exposure that determine subsequent behaviour, as shown by Vernon,[7] Schramm and Taylerson,[8] and others.

Although opinions differ about the relative superiority of iron and steel, no careful observer can fail to note that the character of the attack is different on the two materials, although the ' zonal ' type of attack, which is characteristic of wrought iron, is sometimes met with on highly laminated steel. The object of the present research was to ascertain the causes of the undeniable differences between the corrosion behaviour of wrought iron and steel, and to draw conclusions about the way in which wrought iron can be used to best advantage. At the outset, it was hoped to be able to apply the knowledge obtained to produce cheaply and on a large scale a material which—whether it be called iron or steel—would combine the corrosion resistance sometimes exhibited by wrought iron with the uniformity and general reproducibility of steel.

VARIETIES OF WROUGHT IRON

The balls of pasty material leaving the puddling furnaces are composed of metallic iron and slag, much of which is squeezed out when the balls pass under the ' shingling ' hammer; finally the metal may be rolled or hammered into shape. Frequently, however, there are further operations known as ' piling.' After rolling into plate, the iron is cut up into pieces of convenient length; of these, about six are placed on top of one another to form a pile which is strongly heated. When the pile passes through the rolling mill, the various components become welded together, the intervening oxide on the interior faces being largely squeezed out. This provides ' once-piled ' iron, but it is possible to cut it up again and repeat the operation, thus yielding ' twice-piled ' iron.

Other kinds of wrought iron are known. One is Swedish iron, a very pure slag-free material which is not usually piled. A second material not usually piled is the Aston–Byers iron, which is really a dead-mild steel into which an oxide–silicate slag has been deliberately introduced.

PREVIOUS RESEARCH ON THE ZONAL STRUCTURE OF WROUGHT IRON

It has long been known that wrought iron consists of layers differing from one another in corrosion susceptibility, so that the material tends to develop a wooden structure when exposed to certain environments. Lewis and Evans[9] recognized both *Q* (quickly corroding) and *R* (resistant) zones. Since the orientation of the zones is connected with rolling (Fig. 1), it is convenient to define the three main sections of a rolled slab as:

X face	Perpendicular to rolling direction
Y face	Parallel to rolling direction and rolling plane
Z face	Parallel to rolling direction but perpendicular to rolling plane.

In general, in piled iron the *Q* and *R* zones lie parallel to the *Y* face, but towards the sides of a slab they tend to curve outwards and cut the *Y* face near the corners (Fig. 8). In unpiled puddled bar which has been subjected to much less rolling, this parallelism of the zones is less pronounced.

The earliest Cambridge research (1928)[10] showed that dilute sulphuric acid first attacked the *X* or *Z* faces, eating inwards along the *Q* zones (Fig. 2), the *R* zones being much less attacked and a series of grooves were produced (the labels *Q*, *R*, *X*, *Y*, and *Z* were not at that time used, but are here introduced for convenience). The *Y* faces corroded to a smaller extent, but even here there was a series of parallel fissures, often discontinuous; at the edges of these fissures, metal was invariably undercut. Evidently, along these lines corrosion had penetrated downwards until it reached a layer susceptible to corrosion, and the attack then ate its way along this layer parallel to the surface, undermining the outer resistant layers, which remained almost unattacked.

It was found that if the *X* and *Z* faces of a rectangular slab were protected with balsam, the rate of attack was reduced to about one-fifth of its previous

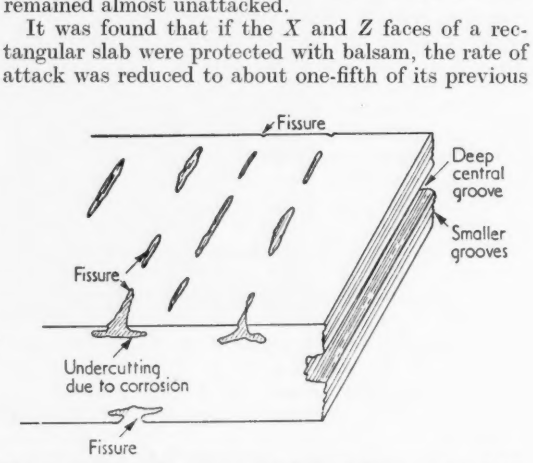


Fig. 2—Schematic representation of the way in which acid preferentially attacks the *Q* zones in the *X* and *Y* faces (after Evans[10])

Table I
ANALYSIS OF THE MATERIALS

Material	C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cu, %
Puddled bar (unpiled)	0·15	0·13	0·02	0·010	0·151	0·19	0·15
Once-piled iron	0·02	0·15	0·02	0·015	0·158	0·17	0·17
Twice-piled iron	0·02	0·09	0·03	0·011	0·117	0·22	0·17
Aston–Byers iron	0·02	0·11	0·04	0·008	0·133	Trace	Trace
Copper-free mild steel	0·21	0·03	0·61	0·036	0·036	0·03	Trace
Copper-bearing mild steel	0·16	0·22	0·65	0·066	0·041	0·08	0·24
Swedish iron	0·034	0·010	0·145	0·015	0·032	0·030	0·010

value. The attack on the *Y* faces began very slowly but gradually increased as the *Q* zones below the surface were reached. Thus one experiment, in which the attack of N hydrochloric acid upon the *Y* faces of iron and mild steel was compared, demonstrated that the dissolution of the iron was much slower at the outset but became faster than that on the steel after 8 hr.

When material is subjected to anodic dissolution by means of an external e.m.f., the corrosion rate is determined by Faraday's law. Specimens of wrought iron and steel were coated with tar paint and a scratch line was traced on each of the *Y* faces parallel to the rolling directions; they were then anodically attacked. The groove cut into the steel was roughly semicircular (Fig. 3), whilst that on the iron was 'stepped.' The depths were 1·44 mm. on the steel and only 0·70 mm. on the iron, although the breadth was, of course, greater than on the steel.

The deflection of the attack in a direction parallel to the rolling plane was attributed to it following a layer that was specially susceptible, rather than to it being held up by one that was specially resistant. Thus the existence of *Q* zones will clearly cause the downward penetration in a given time to be much slower than if such zones had been absent.

The idea of attack being prevented from advancing by meeting a continuous barrier of slag flakes has been favoured by some writers. However, the flakes in wrought iron are inadequate to act as a continuous barrier; in the case of rod the slag may form strings instead of flakes, and these could not obstruct the advance.

These 1928 results are worth quoting, since the wrought iron then used showed the deflecting power of *Q* zones somewhat better than that used in later work, although these gave general confirmation of the effect. The 1928 work, however, did not indicate the causes of the difference between the *Q* and *R* zones. One object of the present research was to ascertain these causes, and in the course of the investigation a further kind of zone, known as a 'very resistant' or *V* zone, was discovered. A description of the new work follows.

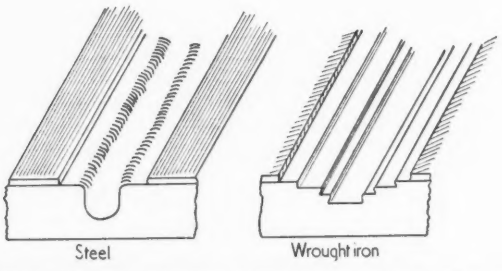


Fig. 3—Different patterns of the attack on iron and steel after anodic corrosion at a scratch line in a protective coating (after Evans[10])

MATERIALS

The materials used included unpiled puddled iron and once- and twice-piled wrought irons, as well as Aston–Byers iron, copper-free and copper-bearing mild steels, and Swedish iron; analyses are given in Table I.

Q AND *R* ZONES

As already explained, the zonal character of corrosion is best displayed either when the total rate of destruction is fixed, as in anodic attack, or in dissolution by a non-oxidizing acid in which the specimen provides its own corrosion current. Such experiments showed *Q* and *R* zones to be present in all samples of British wrought iron; the American Aston–Byers iron did not corrode in a zonal manner.

It was first necessary to ascertain whether the *Q* and *R* zones shown up by anodic dissolution were respectively identical with those produced by acid. Except where otherwise stated, anodic attack was carried out in a solution containing sodium chloride (50 g./l.) and zinc sulphate (100 g./l.), generally at 10 mA./sq. cm. The function of the zinc salt is to ensure that the cathodic reaction (the deposition of metallic zinc) introduces no complications, such as occur when sodium hydroxide is formed at the cathode and travels to the anode; if, by any chance, a trace of sodium hydroxide is formed, it will be destroyed in precipitating zinc hydroxide.

To test the identity of the zones in the two types of corrosion, one half of the *Z* face of a once-piled iron specimen was protected with polystyrene and wax, and the second half was corroded in acid for several days. This second half was then covered with polystyrene and wax and anodic attack was carried out on the first half. Observation showed that the *Q* zones which developed in the anodic dissolution were the linear continuations of those developed by acid, although an 'acid groove' was often about five times as deep as an 'anodic groove' of similar breadth. Apparently some constituent present in the *Q* zones can favour both types of corrosion. Sulphides suggest themselves, since in the acid liquid, and also in the

Table II

ANALYSIS OF A *Q* ZONE AND TWO *R* ZONES TAKEN FROM A TWICE-PILED BAR OF IRON

Kindly carried out by A. Berger at Brussels

	R Zone 1	*R* Zone 2	*Q* Zone	Total Analysis*
Si, %	0·08	0·12	0·13	0·13
P, %	0·075	0·10	0·25	0·15
Cu, %	0·22	0·182	0·19	0·20
Ni, %	0·32	0·27	0·25	0·27
Cr, %	0·020	0·025	0·015	0·020
Mn, %	—	—	—	0·020
Mo, %	—	—	—	0·025
Al, %	—	—	—	0·01
S, %	0·010	0·015	0·010	0·010

*Analysis of the iron block from which the zones have been taken.

presence of the faint acidity which arises from anodic action,[11] they will provide hydrogen sulphide, which is an anodic stimulator.[12]

FUNCTION OF SULPHUR

If the difference between *Q* and *R* zones arises from variations in the amount of hydrogen sulphide evolved, the contrast between them should be diminished if the liquid itself contains hydrogen sulphide. Fresh experiments were carried out, with anodic dissolution in N/1000 sodium chloride containing hydrogen sulphide (zinc salts being omitted for obvious reasons), and with corrosion by acid in which iron sulphide had been placed. In both cases, the attack on the *R* zones was increased and the contrast between the *Q* and *R* zones was diminished, although the *Q* zones were still the more severely corroded. In acid, using an *X* or *Z* section, there was at first a tendency towards uniform dissolution without distinction between *Q* and *R* zones. However, after about a week, thin equi-spaced metallic walls lying parallel to the rolling plane were noticed in the corroded area; these walls were called *V* zones and are discussed later. Anodic dissolution of the iron in the presence of sulphide gave rise to similar phenomena, but in this case the *V* zones were somewhat corroded away.

Sulphur prints of the different sections of iron generally showed dark lines following the *Q* zones. The *Q* zones produced during acid attack were invariably associated with dark lines on the prints, but with anodic corrosion there were some anomalies. The most definite conclusion to be drawn from the sulphur printing was that, if an area was indicated to be sulphur-free, an *R* zone would undoubtedly develop in any subsequent corrosion. Thus the results point to the fact that the *Q* zones contain a much greater amount of sulphide capable of liberating hydrogen sulphide by interaction with acid, than do the *R* zones. In reaching this conclusion, account was taken of the fact that the amount of iron attacked was larger along the *Q* zones than elsewhere, for a large content of attackable sulphur per unit *area* need not necessarily imply a large content per unit *volume*.

Analysis of material machined from the *Q* zones showed, however, that the aggregate sulphur content of the *Q* zones is no higher than that of the *R* zones. The values given in Table II are typical. It would seem, therefore, that the sulphur present in the *R* zones is less 'accessible' to acid than that present in the *Q* zones.

The difference in 'accessibility' could arise in two ways. It might be due to the state of combination—if, for instance, the *Q* zones contained the unstable iron sulphide and the *R* zones the stable copper sulphide. This would tally with the observations of Collari and Antoniolli,[13] who found ten times as much copper in *R* zones as in *Q* zones, but it is not in accord with the figures of Table II, where the copper contents of both kinds of zone are much the same.

It is more likely that the difference between the sulphur of the *Q* and *R* zones respectively is geometric. The metallographic work of Collari[14] indicates that sulphide may frequently be enclosed by slag or form part of a eutectic; in either case it should largely escape attack. If this 'enclosure in an envelope' occurs in the *R* zones but not in the *Q* zones, the difference in behaviour is easily understood.

Unfortunately the zones within an iron bar are so narrow (*see* Fig. 4) as to make it impossible to extract sufficient sulphide from each of the zones for a complete analysis. Therefore, an indirect method of analysis had to be adopted. If geometrical inaccessibility was the main cause of the difference, fine millings from an *R* zone (in which much slag would be cut open revealing sulphide) should evolve more hydrogen sulphide on acid attack than coarse millings from a similar zone. Roughly equal amounts of sulphide should be given off from both kinds of milling from a *Q* zone.

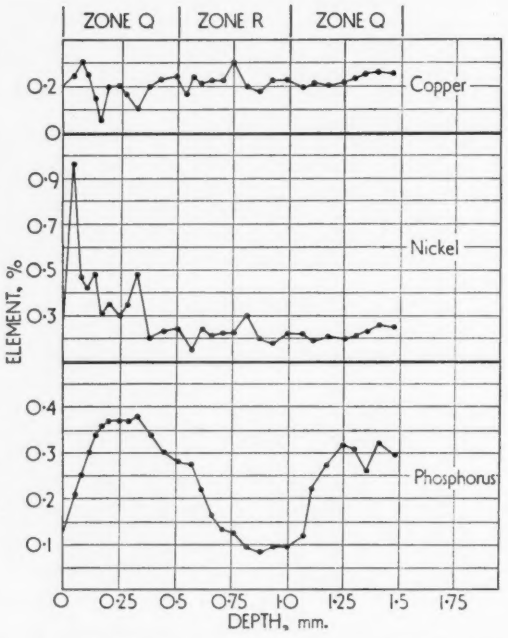


Fig. 4—Variations in copper, nickel, and phosphorus contents of iron in traversing three zones which lie parallel to a *Y* face. Measurements by A. Berger

A sample of wrought iron was chosen in which the *Q* and *R* zones were unusually well defined, and their respective positions were marked on a *Z* face by anodic etching (i.e. anodic dissolution for a short time, during which the *Q* zones were darkened but the *R* zones remained bright). Millings of two kinds were taken from the zones:

(i) Coarse millings at depths increasing by steps of 0·01 in.
(ii) Fine millings by steps of 0·001 in.

The hydrogen sulphide obtained by the action of 6N hydrochloric acid on 0·5-g. samples, allowing ample time for the reaction to become complete, gave the following typical results :

Source	Fine Millings	Coarse Millings
Q zones	0·0185% S	0·0153% S
R zones	0·0147% S	0·0065% S

These values support the view that much of the sulphur of the *R* zones is geometrically inaccessible in the material before milling, since even the ' coarse milling ' procedure must open many of the envelopes and expose the sulphide.

Aston–Byers iron has shown poor resistance to attack in Hudson's atmospheric tests.[15] Its sulphide is largely present in readily attackable, unsegregated form, for dissolution of a block of the iron (in which no slag would be cut open) in 6N hydrochloric acid liberated 85% of the total sulphur as hydrogen sulphide.

DETAILED ANALYSIS OF ZONES

At this stage, great help was rendered by Monsieur A. Berger of the Centre Belge d'Étude et de Documentation des Eaux at Brussels, who applied a special technique, based on a micro-grinder, which enabled samples to be obtained from very narrow strips of the surface, so that *Q* zone material was not contaminated with *R* zone material or *vice versa*. His results (Table II) show that only the phosphorus content showed a marked difference between the zones, being higher in the *Q* than in the *R* zones. This is surprising, for the presence of phosphorus in iron is normally considered to reduce its corrosion rate. Apparently the deleterious effects of sulphur completely mask any benefit provided by the phosphorus.

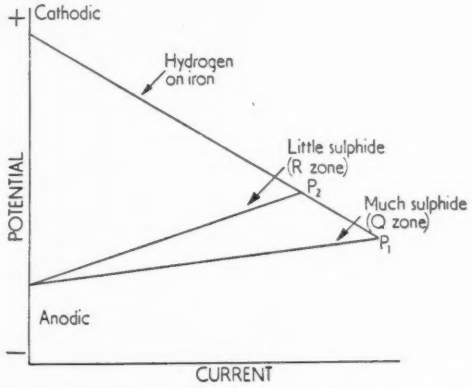


Fig. 5—'Intersection curves' illustrating the cause of the anodic potential taken by *Q* zones

It is not certain how far phosphorus was present in solid solution in the iron or as phosphate in the slag. Difficulty was encountered in estimating each element in the slag and iron matrix separately. Only the average compositions of the different zones were determined, but great inhomogeneity exists within the zones themselves, as is clear from Fig. 4; this illustrates the variations in copper, nickel, and phosphorus in traversing three zones of an iron which lie parallel to a *Y* face.

FURTHER STUDIES OF *Q* AND *R* ZONES

If an *X* or *Z* section of an iron was anodically corroded at a high current density (100 mA./sq. cm., for instance), the contrast between the *Q* and *R* zones disappeared. At lower current densities, the anolyte would become acid and hydrogen sulphide would be evolved at the *Q* zones; thus attack at these areas would be enhanced and grooves would result. At the higher currents, however, the rate of attack on the whole section would be so rapid that the effects of the liberated sulphide would be inappreciable. Lewis and Evans[9] found some wrought iron which anodically dissolved in a very even fashion; their observation is readily explained, for they used rather high current densities, namely 50 and 200 mA./sq. cm. The effect may also account for the excellent deflection obtained by Evans[10] in 1928. Possibly the current density at a scratch line has been far too high in all the attempts to repeat this experiment, and consequently iron has corroded similarly to steel.

It has been proved that current is definitely passing between the zones, causing anodic attack on the *Q* zones and cathodic protection on the *R* zones. Two *Z* specimens from once-piled iron were subjected to anodic corrosion, one for a short time, so as to give shallow trenches at the *Q* zones, and the other for a long time, so that the trenches were deeper. Both were lightly polished so as to bring the *R* zone ridges to a single level; on the first specimen, the *R* zones were masked with polystyrene, the *Q* zones being left bare, whilst the second one had its *Q* zone grooves filled with a paste of china clay and paraffin wax in xylene, leaving the *R* zones uncovered. The rest of the specimens were completely masked. When the two specimens, representing *Q* and *R* material respectively, were immersed in N/10 sodium chloride and connected to a microammeter, a current of 100μA., dropping to 10μA. in 24 hr., was registered.

A similar experiment was performed in which the iron had been very little corroded; the positions of the *Q* and *R* zones were determined by anodic etching. The same result was obtained, namely that the *Q* zones were always anodic. Collari and Antoniolli[13] have also demonstrated currents flowing in the same direction between the zones. Measurement of the corrosion potentials of the two zones indicated that the *Q* zones were always 40 mV. less noble than the *R* zones.

The reason for the anodic polarity of the *Q* zones is easily understood if the sulphide in these zones is accessible. The potential of each zone is a compromise value represented by the intersection of local anodic and cathodic polarization curves (Fig. 5). Hydrogen sulphide, liberated at the *Q* zones, is an anodic

Table III

ANALYSIS OF A *V* ZONE TAKEN FROM TWICE-PILED IRON

Kindly carried out by A. Berger at Brussels

Column 1. 0·5 mm. to one side of the *V* zone
„ 2. 0·5 mm. to the other side of same zone
„ 3. Mean analysis of zone
„ 4. Analysis of middle of zone
„ 5. Total analysis of iron

	1	2	3	4	5
Si, %	0·130	0·085	0·10	0·075	0·12
P, %	0·10	0·09	0·16	0·23	0·15
Cu, %	0·21	0·22	0·43	0·75	0·20
Ni, %	0·259	0·29	0·99	2·32	0·27
Cr, %	0·015	0·015	0·015	0·022	0·020
S, %	—	—	0·01	—	0·010

stimulator rendering the anodic curve less steep, so that the intersection occurs at a lower (more anodic) potential (P_1) than in the case of the *R* zones (P_2) where there will be little hydrogen sulphide. Therefore, when once the anodic corrosion on the *Q* zones, promoted by their 'accessible sulphide,' has been established, the *R* zones will receive cathodic protection.

The fact that unpiled bars of iron also contain *Q* and *R* zones proves that the formation of these zones cannot be primarily due to the piling process. Indeed, Lewis and Evans[9] were unable to correlate the number of times an iron had been piled with the number of zones within the iron. The zones must originate in the course of puddling. This process is carried out on a very small scale by hand, and the fact that macrohomogeneity of the iron ball in the puddling furnace is not obtained causes no surprise. The inhomogeneity is retained in the rolled bar of iron. However, the reason for the fortuitous segregation of sulphide in the oxide–silicate slag in the *R* zones is not known, which is unfortunate, for this fact really accounts for the zonal behaviour of iron.

V ZONES

As would be expected, the addition of hydrogen sulphide renders the *R* zones susceptible to acid attack. On placing an *X* or a *Z* section of a piled iron in acid containing sulphide, the whole surface rapidly darkened with the exception of several equi-spaced bright lines, lying parallel to the *Y* face. After considerable corrosion, it was found that the 'lines' had developed into 'walls' which were almost unattacked. The zones were very thin; in an *X* section they were deflected in the same fashion as the *Q* and *R* zones (Fig. 8); where the zones approached the sides of a bar they became much thicker than elsewhere.

These walls, the *V* zones, only occur in piled iron, and their positions were found to correspond to the planes along which welding of the pile components had taken place. In some cases, the welding planes could be clearly detected on highly polished *Z* sections of an iron when examined by reflected light; the planes were correlated with the positions of the *V* zones after corrosion of the iron. Also, an iron piled 'nine-high' (having eight interfaces between the component bars) contained eight *V* zones.

Berger's analyses of *V* zones are given in Table III; *V* zones are rich in nickel and copper (and also in phosphorus, but this is most probably present in the numerous phosphate inclusions within the zones). The widths of the samples cut from the zones for the analyses was only 0·01 mm. in some cases. Probably if the samples could have been taken from even narrower layers representing the exact centres of the zones, still higher values would have been obtained. We must regard the *V* zones as horizons composed of a low-alloy steel; the traverse (Fig. 6) carried out by Berger shows nickel contents reaching 2·6%.

The origin of the enrichment in these valuable constituents, for which no special price has been paid by the makers of wrought iron, can be suggested. The puddled iron contains unimportant amounts of nickel and copper, derived from the ore. When the components of the pile are strongly heated to the temperature (1500° C.) appropriate for the welding process, a form of selective oxidation takes place. The thick oxide scale produced consists essentially of oxides of iron, since the noble elements either remain in the metallic phase just below the scale, or, if they enter the oxide phase temporarily, are soon reduced either by the iron below, as shown by Pfeil,[16] or by iron oxide, rich in iron[17]:

$$\mathrm{Fe} + \mathrm{NiO} \rightarrow \mathrm{FeO} + \mathrm{Ni}$$
$$\mathrm{FeO\ (iron\text{-}rich)} + \mathrm{NiO} \rightarrow \mathrm{FeO\ (iron\text{-}poor)} + \mathrm{Ni}.$$

When the molten oxide (which is extremely fusible owing to the presence of silicates) is squeezed out from between the components, the two enriched surfaces weld together to produce a single enriched layer, thus explaining the high nickel and copper values which are found. Sometimes, however, the

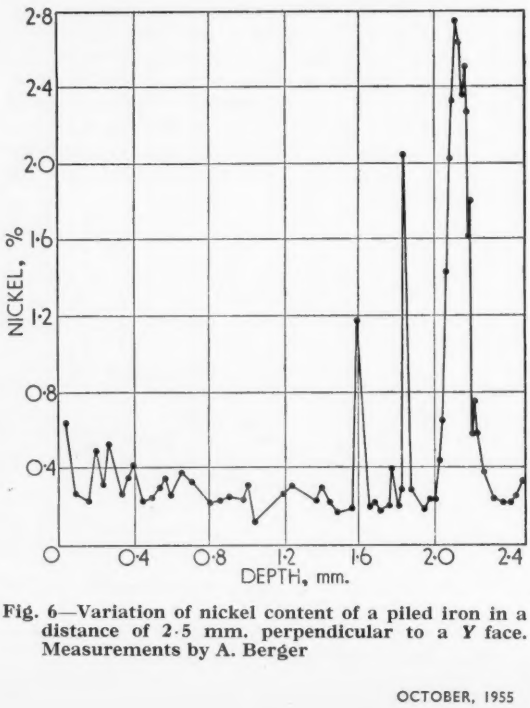


Fig. 6—Variation of nickel content of a piled iron in a distance of 2·5 mm. perpendicular to a *Y* face. Measurements by A. Berger

welding of adjacent enriched areas is incomplete, and in these instances a double-walled *V* zone results.

The *V* zones thus represent the places where the components of the pile become welded together, whilst the *Q* and *R* zones (which occur even in unpiled iron) are connected with variations in the puddling slag. There is no enrichment of nickel or copper in an *R* zone (Fig. 4).

Unfortunately, conditions on the outer surface are unfavourable to the retention of a *V* zone, since if the iron oxide scale is rolled off or otherwise removed the enriched layer, exposed directly to the air, is likely to be oxidized and removed in its turn. On hand-forged iron, the oxide scale is beaten on to the metal surface and a continuous outer *V* zone results.

Particularly good *V* zones were sometimes observed on British irons at the places where *Q* zones abutted on to the metal surface. Here the sulphide may have enhanced the oxidation, and thus established conditions extremely favourable for the enrichment.

Repiling piled iron will produce new *V* zones, but the copper and nickel concentrated in the original zones will diffuse back into the metal and no added improvement may result. Lewis and Evans[9] even demonstrated that twice-piled iron had a smaller deflecting power than the once-piled material.

On once-piled bar, besides the *V* zones, other small local areas contain relatively high amounts of alloying elements (e.g. nickel up to 0·6%), but these areas are not resistant to attack by acid containing sulphide. Such local concentrations must be attributed to an inhomogeneity caused by the puddling process.

THE PROBABILITY OF CORROSION OF WROUGHT IRON

The probability that corrosion will start on a small area is not the same thing as the velocity with which it will proceed when once started, a matter discussed by Mears[18,19] and Evans.[19] The probability will be affected by iron itself in two ways since (*a*) differences exist between the probability figures of the various zones, and (*b*) the rolling or forging scales can help to prevent initial attack.

Some indication that the value of wrought iron might depend on a low ' probability,' as opposed to a low conditional velocity, may be found in the early work of the Wrought Iron Tubing Inquiry Committee,[20] and in the first Cambridge research.[10]

Attempts were made to measure the corrosion probability on polished iron surfaces with Mears's ' square drop ' method,[18, 19] but these were not very successful. Mears and Evans obtained their square drops by ' ruling ' the surface with sets of lines using a wax solution so as to obtain a ' chessboard ' which would retain a drop of liquid on each of the different squares, when flooded and tilted to allow surplus liquid to run off the waxed lines. In the present work, two rubber stamps (providing ' chessboards " of 3-mm. and 2-mm. squares, respectively) were made (Fig. 7); when moistened with a solution of paraffin wax in xylene, such a stamp printed the appropriate network of waxed lines in a few seconds.

Probability measurements, using drops of distilled water or M/40 sodium bicarbonate solution, on wrought-iron surfaces (polished down to 000 emery and degreased in xylene) provided figures only slightly below that of a mild steel; Mears obtained a similar result.[18] Aston–Byers iron furnished a very high probability number. Such results are not surprising, since the drops were so large that each one covered both *Q* and *R* zones; it was found that corrosion really began at points on *Q* zones and not on *R* zones. The situation was further complicated by the possibility that the corrosion of the *Q* zones cathodically protected the *R* zones. Consequently, a new method, suggested by the work of Whitton,[21] was developed, based on an acid film so thin that the mutual interaction of the zones could be neglected.

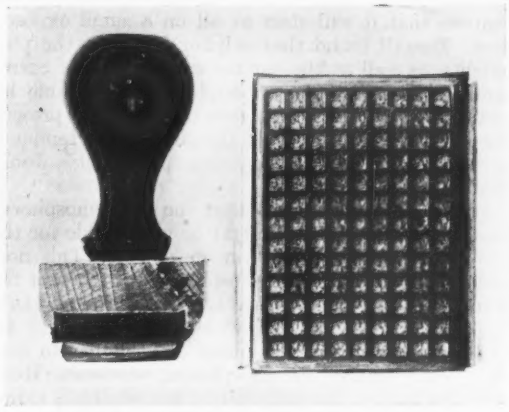


Fig. 7—Rubber stamps for making ' chessboards ' of waxed lines

Polished surfaces of iron were covered with a thin layer of a mixture of 0·001N sulphuric acid with five times its volume of alcohol; the alcohol evaporated leaving a layer of dilute acid thin enough to produce interference tints. The specimens, placed over water in a vessel of desiccator type, developed rusting more readily on the *Q* than on the *R* zones; similar experiments on steel showed that the probability of attack (as measured by the number of points of rusting per unit area) was greater than that on the *R* zones of wrought iron, but less than that on the *Q* zones.

Other simple observations confirmed the high probability figures of *Q* zones. For instance, a *Z* section of iron, on being allowed to corrode in the atmosphere, at first rusted preferentially along the *Q* zones.

The thin-film method did not provide information on the *V* zones. However, the zones seem to possess an extremely low probability of attack; specimens of polished *X* or *Z* sections of piled iron exposed in the laboratory slowly rusted over their entire surfaces with the exception of the *V* zone areas, which still appeared bright after many months (Fig. 9). Also, on gently rubbing off the loose rust present on a polished *Z* section (after exposure out of doors for a day during wet weather) the *V* zones were seen to be quite unrusted (Fig. 10).

Apparently the different state of the sulphur in the *Q* and *R* zones accounts not only for the difference in velocity of corrosion (once started), but also for the

chances that it will start at all on a small exposed area. Mears[18] found that sulphur increases the probability as well as the conditional velocity of corrosion. In the *V* zones, no sulphide is detectable by metallographic tests; and even if any were present the high copper content of the zone would render it harmless and thus a very low probability would result.

It was felt at one time that the high phosphorus content of wrought iron might be responsible for the low probability at points on an *R* zone. This now seems improbable, since phosphorus is higher in the *Q* zones than in the *R* zones. It was also thought that the film formed on the wrought iron during air exposure might be a phosphate film, similar to that obtained in commercial phosphating processes. However, samples of film stripped by the alcoholic iodine method of Vernon, Wormwell, and Nurse[22] were found by electron diffraction to consist of γ ferric oxide, like those obtained from ordinary iron; no phosphate could be detected, although a little may have been present at the oxide/metal interface.

A second factor which may govern the probability of attack on iron is the protection possibly provided by the surface oxide scale. The scales on wrought iron have a glazed, enamel-like appearance owing to the presence of silicates and phosphates; they seem much more resistant to removal by weathering than those present on steel. Thus the scale may well offer protection to the underlying iron in the opening stages of exposure; if the rate of descaling is negligible and the oxide scale is perfectly continuous, the probability of corrosion on the iron will be zero. The quality of the scale determines the probability that corrosion will begin; a smooth adherent scale provides a low probability value, but a damaged scale permits rapid rusting.[18] The irons used in the present research possessed similar features; the scale always consisted of two layers, one of which was readily removed, and another, immediately next to the iron, which was very adherent, a fact noted by others.[23] If this inner layer was continuous, no attack started on the iron. Very inferior surface *V* zones exist under badly damaged rolling scales; however, beneath smooth scales the zones cover larger areas on the iron.

Collari and Fongi[24] have suggested that the oxide in the scale reacts with the phosphorus in the iron matrix to give phosphate at the boundary between the two; this might also help to reduce the probability. Griffiths[25] thinks that the presence of phosphorus in iron improves adhesion, a fact which might account for the greater adherence of rolling scale to iron than to steel.

THE CAUSES OF THE RESISTANCE OF WROUGHT IRON

The overall rate of corrosion of any metal is dependent on (*a*) the probability of attack starting in the first place, and (*b*) the rate at which the metal subsequently corrodes.

The probability of corrosion is controlled by several factors, some of which are contributed by the metal itself and some by external agencies; the former have been dealt with in the previous section, the latter include environment and protective coatings.

The part environment may play has been mentioned in the opening section. In dry unpolluted environments, both iron *and steel* show excellent resistance; if the material is covered with a scale, the descaling rate is extremely low. It is likely that the atmospheres of many towns in warm countries, and probably those of British towns in mediæval times, must be regarded as alkaline with ammonia. Iron or steel exposed above a solution of ammonia remains unrusted.[26] The trace of ammonia may be insufficient to stop corrosion over a large surface, but if only small areas of metal are exposed, the rest being covered with scale or paint, the probability of rusting may be be very low.

Protective coverings can be broadly grouped into two classes: (*a*) paints, and (*b*) galvanized coatings. Iron carries much greater weights of all types of coating than steel, for its surface is very rough and the slag helps the adhesion. The greater thicknesses of zinc used in the past[27] will have rendered better service than the thinner coatings which are common today. Even if gaps in a paint coat (' holidays ') do exist corrosion may still fail to start if they chance to lie over *V* or *R* zones, where no sulphur is available to stimulate corrosion.

The scale on iron is a unique kind of protection. Much old iron was put into service in the condition in which it emerged from the forge (i.e. scale-covered) and this would help the iron to resist attack in environments which were mild enough not to cause descaling. Even in rather corrosive conditions, the scale slows down the initial rusting on iron.

If the metallic surface layer of an iron is a *V* zone, as on old or hand-forged irons, the probability will be reduced considerably. On most British irons, the surface layers are normally *R* zones, but even these have a lower probability figure than mild steel. At places where *Q* zones cut the surface of the iron, rapid corrosion can begin.

When attack has got under way, the zonal nature of the iron will affect matters. However, it must be remembered that in the very old iron there are no zones at all within the material, and the same is true for Aston–Byers iron. Also, in unpiled puddled iron only *Q* and *R* zones are found.

Pronounced *Q* and *R* zones are revealed on iron during corrosion by acids, anodic attack with an applied current, or galvanic corrosion by connection with a noble metal; even in dilute electrolytes iron corrodes zonally. Iron will only show a good resistance if the material is carefully used; otherwise, attack may be more rapid than on a mild steel. The plane of the zones must be perpendicular to the direction of corrosion for rusting to be deflected.

The *V* zones may act as a barrier to corrosion, provided that they are not so thin or discontinuous as to be ineffective. The idea of such zones deflecting attack is not new; it was originally suggested by Siemens[28] (who, however, was unaware of the highly resistant nature of the zones, and merely called them ' welding lines '). Examples have been found where corrosion had stopped or had become very slow at what were almost certainly the first *V* zones to be encountered. A particularly good example was brought to the authors' notice by Dr. W. H. J. Vernon

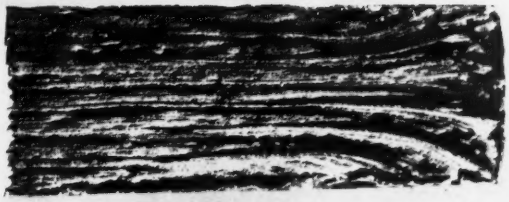


Fig. 8—*X* section of iron showing the way in which the zones are deflected towards the sides of a bar

Fig. 9 *V* zones unrusted on a *Z* section of piled iron, exposed indoors for a year × 45

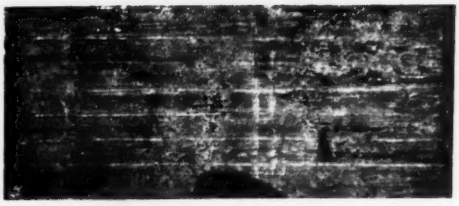
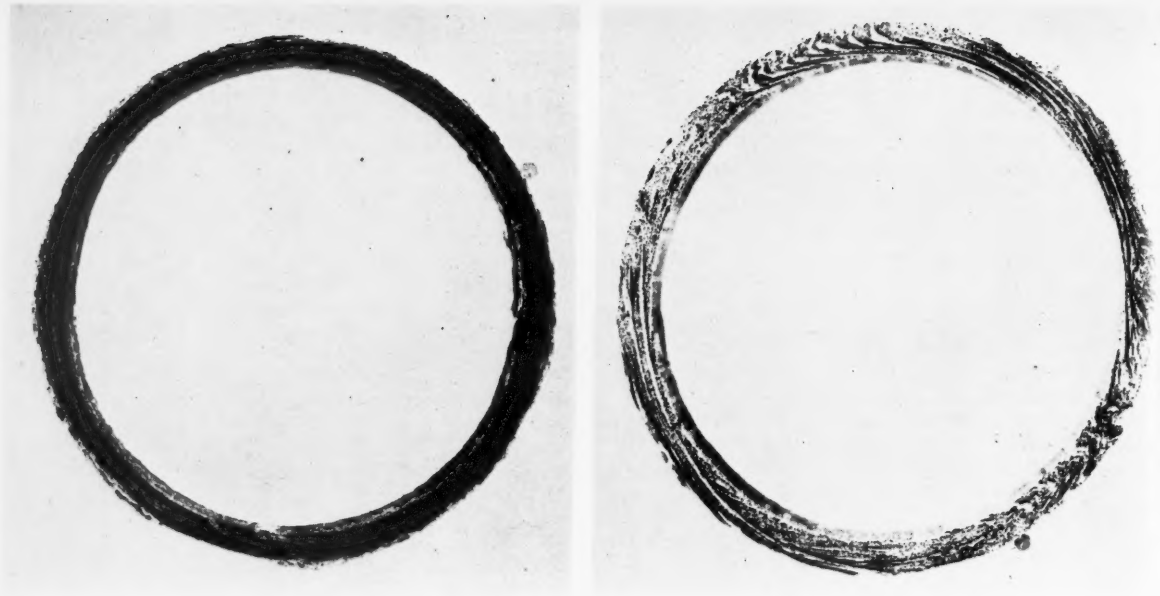


Fig. 10—*V* zones unrusted on a *Z* section of piled iron after exposure outdoors in wet weather



(*a*) (*b*)

Fig. 11—Zonal pattern of (*a*) a lap-welded tube, (*b*) an extruded tube. Original photographs taken by Dr. G. Butler and reproduced by permission of the Director, Chemical Research Laboratory, Teddington *Approx. actual size*

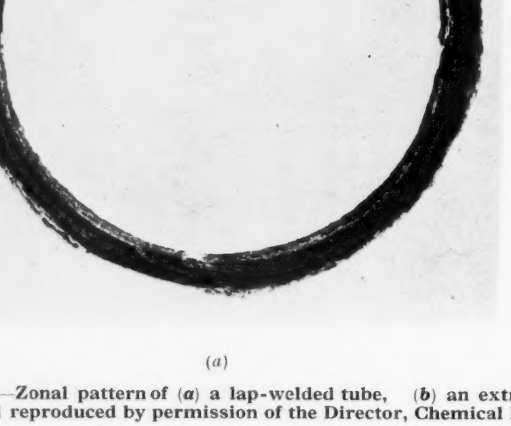


Fig. 12—Sulphur print of a boiler tube showing the orientation of the zones within it
Actual size

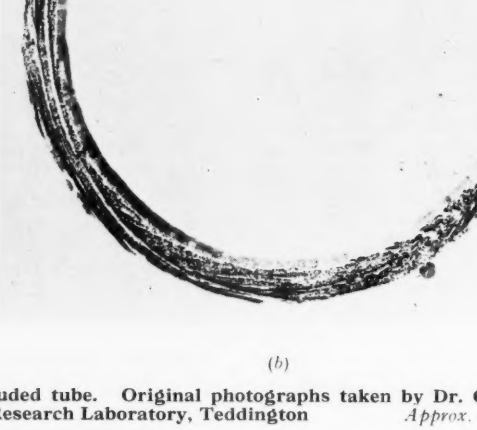


Fig. 13—Deeply acid-etched section of boiler tube in Fig. 12, also showing the zonal pattern

and his colleagues at the Chemical Research Laboratory, Teddington, who were investigating the corrosion of boiler tubes for the British Shipbuilding Research Association. This was a lap-welded wrought-iron marine-boiler tube (Fig. 11*a*) which had given excellent service for about 30 years; under similar conditions, tubes of steel (the material which has to be used nowadays) often fail by pitting in much shorter times.

The time taken for corrosion to reach a *V* zone within the metal may be considerable. In Hudson's atmospheric tests, the standard time of exposure was five years, but this was probably insufficient for rusting to have reached the first *V* zone; in the highly corrosive atmosphere of Sheffield, on the once-piled iron used, it would have required about 15 years exposure before the superiority of iron over steel would even start to become evident. Such a fact explains why iron in practice often gives much better service than field tests would predict.

POTENTIAL VALUE OF WROUGHT IRON

Wrought iron is a material which behaves differently from steel and which may have special value provided that it is used with proper appreciation of its directional properties. Every manufacturer and every designer should contrive that as far as possible only *V* or *R* zones are exposed to corrosive agencies, and that all places where *Q* zones cut the surfaces (as at the sheared edges of plates) thick and reliable protective covering shall be applied. The *Y* faces of plates require less careful protection since, if a 'holiday' in the coat should occur, the very small bare area is most likely to consist of *R* zone material, and the risk of attack starting is relatively small. The user, also, in designing his structures must think out the geometry of the combination in such a way as to keep the various zones perpendicular to the direction of corrosive attack. Figure 11 shows sections of two wrought-iron boiler tubes. That in Fig. 11*a* has been lap-welded so that the zones are arranged in an annular manner and good service can be expected; however, in Fig. 11*b* (a drawn tube) zones cut the surface and rapid pitting may occur. The orientation of the zones within the iron can be readily determined by taking sulphur prints or deeply etching a section of the iron (Figs. 12 and 13).

As explained, it is most desirable to have a complete *V* zone on the surface of iron, but this is rarely the case with material made nowadays. If iron was hammered rather than rolled into shape, the formation of outer *V* zones would be assisted. 'Roll knobbling' produces an effect similar to that of hammer forging, and its adoption could again lead to the same result.

PROSPECTS OF LARGE-SCALE PRODUCTION

It is unlikely that steelmakers, at a time when emphasis is on output, could be persuaded to adopt the traditional wrought-iron process, in which output figures are low, even when considered in relation to the small size and small cost of the furnaces. Nor is it likely that they would modify their own processes in such a radical way as to embody any lessons which a careful study of the wrought-iron industry might provide. The same effort and expense could probably be spent to better advantage in other directions.

Perhaps the best hope of applying the information obtained in the present research is to be found in the existing wrought-iron industry. It is widely believed that this is doomed; it is asserted that new men are not learning the art of the puddling industry as quickly as the old ones leave it, and that in a few decades puddling may be a thing of the past. It certainly seems possible that wrought-iron works may shortly have to close down the puddling furnaces, and either discontinue the rest of the procedure or adopt steel plate as a raw material for piling.

Now the use of steel to produce a counterfeit wrought iron has been practised on many occasions in the past, and has been rightly deprecated by those who were producing the traditional article. But a frank production of piled steel, retaining the process now used for wrought iron except in so far as it must be modified to obtain effective welding of the steel components, might provide a material capable of improved service under suitable conditions. Doubts have been expressed about whether a pile of steel components containing no puddling slag would weld up satisfactorily. Indeed, it may be difficult to heat and roll steel at the sufficiently high temperatures needed; iron is rolled at a temperature about 300° C. higher than steel. However, a piled iron has been successfully produced from components consisting of nearly slagless Swedish iron[2]; here the reheating temperature was 1340° C. Although modification might well be necessary—and perhaps much research on a semi-technical scale—before piled steel could become a reliable material, there would be at least a good chance of overcoming the difficulties, particularly in view of the increased understanding of welding processes available today.

It should not be pretended that piled steel will be the same as piled iron. Since there will be no puddling slag, the presence of *Q* and *R* zones cannot be expected, and the sulphur will not be shielded in any part of the material. Corrosion resistance could only depend on *V* zones, which means that on thick plate no special advantage over steel will appear for a number of years, whilst, if anything, more protective painting will be needed at the sheared ends to avoid attack penetrating along the layers between the *V* zones, with subsequent swelling and foliation of a type sometimes experienced in light alloys. It is mainly for situations where, on ordinary steel, there would be rather rapid pitting and perforation that piled steel, carrying internal *V* zones of virtually alloy-steel character running parallel to the surface, holds out a certain promise. The lap-welded tube of the type shown in Fig. 11*a* might, if constructed of piled steel, give service similar to that of piled iron, sideways deflection being caused by the *V* zones alone; clearly however, much testing would be needed before they could be relied on.

CONCLUSIONS

The resistance of particular objects or structures of wrought iron is often due to a combination of favourable factors, some of which are contributed by the iron, some by protective coatings, and others by

the environment. Iron itself possesses several unique features, all of which help to give it resistance *in certain circumstances*.

The possible reasons for the durability of a given example of iron may be summarized as follows.

Environment

In dry unpolluted atmospheres the rate of corrosion will be negligible; if an intact scale is present on the object, no attack will occur. At gaps in the scale or on bare iron a thick protective film can be built up which may afford protection if at a later stage the environment becomes less favourable.

Low Probability of Attack

Even in somewhat aggressive environments, the chances of attack beginning on wrought iron are less than those on other ferrous materials. This low probability of corrosion is controlled by several factors:

(i) The presence of an adherent uncracked smooth scale provides protection, particularly in the early stages of exposure

(ii) The *V* zones have a very low probability of corrosion; if an intact *V* zone is present on the outside of an iron specimen, the chances of attack are small. If such a zone is absent (as is generally the case on modern British iron), the iron may still have a lower probability of corrosion than steel because the surface layer is frequently an *R* zone.

Zonal Attack

If corrosion does occur on iron, this may take place at a slower rate than on steel owing to the zonal nature of the iron.

In acidic or anodic attack, or even in dilute salt solutions, *Q* and *R* zones are able to deflect corrosion provided that the plane of the zones in the iron faces the corrosive agent. Incorrect orientation leads to rapid attack.

Besides deflection of the attack by the *Q* and *R* zones, the *V* zones can, in certain cases, provide a barrier at which corrosion stops or continues to advance at a much reduced rate.

Protective Coatings

Protective layers have often been found on supposedly resistant iron; in some instances, the coatings on iron render better service than those on steel. Even when the coatings break down, zonal attack may occur, giving iron an added superiority over steel.

Acknowledgments

This research could hardly have reached success but for the extensive co-operation of friends in many places. In particular, the skilful and time-consuming micro-analyses carried out in Belgium by Monsieur A. Berger and his colleagues by their special technique made possible definite conclusions about the nature of the zones in wrought iron. Further valuable help on the analytical side has been afforded by Mr. S. Ignatowicz of the British Iron and Steel Research Association, Battersea Laboratory, whose methods have been adopted at Cambridge; by the Brown-Firth Research Laboriatories, Sheffield; and by the Bragg Laboratory, Sheffield. The electron-diffraction studies were very kindly carried out by Mr. R. K. Hart at Cambridge University.

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The Reaction of Carbon and Oxygen in Molten Iron

By E. T. Turkdogan, L. S. Davis, L. E. Leake, and C. G. Stevens

SYNOPSIS

The carbon–oxygen equilibrium has been studied in molten iron under carbon monoxide at 1 atm. pressure at 1540° and 1640°C. and at carbon concentrations up to 3·6%. The equilibrium constant for the carbon–oxygen reaction has been evaluated from available data. The activity coefficients of dissolved carbon and oxygen are affected materially by the carbon content of the metal. Decarburization of iron in air and in an oxygen/argon mixture, in alumina crucibles, was found to require an immeasurably small quantity of excess oxygen to proceed. The surface condition of the crucible containing the melt had a definite influence on the rate of carbon removal. One of the factors responsible for the sluggishness of the carbon–oxygen reaction in open-hearth steelmaking practice is believed to be the difficulty of forming carbon monoxide bubbles, which can be initiated only from suitable crevices on the furnace hearth, unmelted charge, pores of the lime added, etc. 1144

THE DECARBURIZATION OF IRON has been studied many times on both laboratory and works scale, and reference should be made to Schenck[1] and Marshall and Chipman[2] for detailed reviews of early work.

An intriguing phenomenon associated with the carbon–oxygen reaction is, as indicated by Fetters,[3] that under steelmaking conditions there appears to be more oxygen in the metal for a given carbon concentration than corresponds to equilibrium conditions. It was also pointed out by Larsen[4] and Turkdogan and Pearson[5] that the oxygen content of the metal calculated from the ferrous oxide activity of the slag is much higher than that obtained by analysis. These findings have led to the conclusion that under steelmaking conditions the carbon–oxygen reaction is relatively slow and that decarburization can proceed only in the presence of a large excess of oxygen.

Although the above-mentioned facts are now well recognized, it is not yet clear whether the carbon–oxygen reaction is intrinsically sluggish, or whether the conditions in open-hearth steelmaking are unsuitable for rapid decarburization.

This paper deals with the findings of some laboratory experiments on the interaction of carbon and oxygen under various conditions.

EXPERIMENTAL

In experiments where the atmosphere consisted of argon, argon–oxygen, or carbon monoxide, a molybdenum wire wound resistance furnace was used. The reaction tube assembly was the same as that described elsewhere.[6] In experiments carried out in air, heating was supplied by a high-frequency induction coil. In all these experiments 1½-in. dia. crucibles containing 300 g. of metal were used.

In all cases the temperature was measured by means of a Pt/Pt–13% Rh thermocouple in a recrystallized alumina sheath. In the molybdenum furnace, the bottom of the crucible containing the melt was in contact with the thermocouple sheath, and during calibration no difference could be detected between the temperature readings obtained with this external thermocouple and with one immersed in the melt. The temperature was controlled automatically within ± 2° C. In the H.F. induction furnace, the thermocouple sheath was kept in the melt throughout the experiments. Here the temperature control was within ± 5° C.

The materials used were B.I.S.R.A. iron (*AG*) of the following composition: 0·008% C, 0·002% Si, 0·005% Mn, 0·008% S, 0·001% P, 0·01% Ni, 0·001% Cr, 0·006% Cu, 0·001% Al, other impurities totalling less than 0·01%; spectrographically pure graphite (from Johnson, Matthey and Co., Ltd.); carbon monoxide, argon, and oxygen from cylinders. The gases were dried with Anhydrone before use.

The metal samples, taken by the technique described elsewhere,[7] were generally free from blowholes. The sound samples were analysed for oxygen by the vacuum fusion method, duplicate estimations agreeing within ± 0·0006%. Samples containing blowholes were rejected. The metal was analysed for carbon by the normal combustion method.

RESULTS

Two series of experiments were conducted. In the first, iron containing various proportions of carbon and oxygen was brought to equilibrium, or apparent equilibrium, with a stream of carbon monoxide or argon at 1 atm. pressure at 1540° and 1640° C. In the second series of experiments, using air or argon plus oxygen mixtures at 1 atm. pressure, the samples were taken frequently during the course of decarburization.

Carbon–Oxygen Equilibrium

Marshall and Chipman[2] studied the carbon–oxygen equilibrium in molten iron under pressure up to 20

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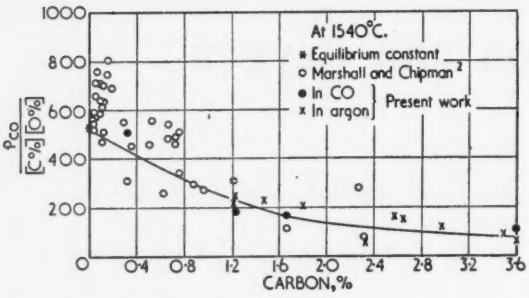

Fig. 1—Carbon–oxygen equilibrium ratio related to carbon content of molten iron at 1540° C.

atm., within the temperature range 1450–1700° C., and up to about 2·3% carbon. Additional experiments were, however, considered desirable, particularly at higher carbon concentrations.

To ensure that equilibrium was established in the iron–carbon–oxygen melts, 1 hr. was allowed to elapse after making any additions to the metal and before sampling, preliminary experiments having shown that no changes in composition were detectable after holding for ½ hr.

Some of the melts which contained carbon and oxygen as a result of exposure to carbon monoxide were then kept in a stream of argon at 1 atm. pressure for 16 hr. before sampling.

The present experimental results at 1540° C., together with those of Marshall and Chipman,[2] are plotted in Fig. 1, where the ratio $p_{CO}/[C\%][O\%]$ is plotted against the percentage of carbon. In the case of the argon atmosphere, the pressure of CO has been arbitrarily assigned a value of 1 atm. The term $p_{CO}/[C\%][O\%]$ is the 'equilibrium ratio' of the following reaction

$$[C] + [O] = CO(g) \quad \ldots\ldots(1)$$

As pointed out originally by Marshall and Chipman,[2] the concentration of dissolved carbon affects its own activity coefficient as well as that of oxygen, and as a result the equilibrium ratio defined above should be a function of the carbon content of the iron; Fig. 1 illustrates this relationship. The point on the ordinate at zero carbon is the true equilibrium constant at 1540° C.

The results on melts under argon indicate that, although the metal was kept in a flow of inert gas (free of oxygen) for a prolonged period (16 hr.), a measurable quantity of oxygen was left in the metal. There had been during this period only a small amount of decarburization, i.e. about 0·1% of carbon. This shows that the loss of CO from the surface of the melt is very slow. The oxygen for this decarburization must have come from reduction of the alumina crucible and, in fact, on introducing a small amount of oxygen to the system, a solid slag was formed immediately. This disappeared on re-introducing argon, and carbon monoxide was found in the exit gas. Some of the samples obtained from melts kept in argon were analysed for aluminium, which was of the order of 0·2%. The presence of aluminium in the melt should have influenced the activity coefficients of carbon and oxygen, nevertheless the carbon and oxygen contents were such as corresponded to equilibrium with carbon monoxide at 1 atm. pressure.

Figure 2 gives the relationship between the equilibrium ratio and carbon concentration at 1640° C. in experiments in carbon monoxide and argon. The point of intersection with the ordinate is the true equilibrium constant.

Carbon/Oxygen Relationship During Decarburization

Three melts were conducted in an H.F. induction furnace to study the carbon drop in air at various temperatures. In Fig. 3 carbon percentage is plotted against the time of sampling, zero time being that at which a temperature of 1540° C. was reached.

In two separate experiments, using smooth recrystallized alumina crucibles, the rate of carbon drop was identical at the same temperature. On increasing the temperature at *a* to 1615° C., there was a rapid change in the rate of decarburization, as would be expected. Further change of temperature at *b* to 1660° C. did not seem to affect the rate of carbon removal.

In the third experiment the alumina crucible used had a rough internal surface, produced by coating with a thin layer of alumina cement. In this container the rate of decarburization was somewhat higher, as may be seen from Fig. 3. Change of temperature at *c* to 1620° C. increased the rate of carbon removal.

During decarburization there was no sudden gas evolution, indicating the absence of supersaturation of the melt with respect to carbon and oxygen. Even during sampling operations, no gas evolution from the melt was observed.

In the above experiments, special samples were taken one after another from the surface and the bottom of the crucible. As indicated by the points in Fig. 3, there is no carbon concentration gradient in the melt. The samples taken from the surface by means of a small silica spoon were not suitable for oxygen determinations, but it is most unlikely that there will be any difference in oxygen content of the samples taken from different parts of the bath.

The main purpose of this work was to determine the magnitude of the excess oxygen or the extent of departure from carbon–oxygen equilibrium during the course of decarburization. A number of samples were analysed for oxygen, and in Fig. 4 the equilibrium ratio is plotted against the carbon concentration, the pressure of CO being taken as 1 atm. Some of the results were obtained from melts under a 10% oxygen + 90% argon mixture. The curves in Fig. 4 are reproduced from Figs. 1 and 2 and represent the relationship under equilibrium conditions. It is quite

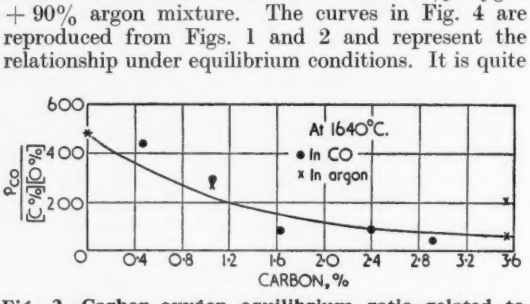

Fig. 2—Carbon–oxygen equilibrium ratio related to carbon content of molten iron at 1540° C.

clear from Fig. 4 that the carbon–oxygen reaction is fast under the experimental conditions. In other words, the rate of decarburization is so fast that only an immeasurable quantity of excess oxygen is required to drive the reaction forward, or so fast that it maintains carbon and oxygen concentrations which are indistinguishable from those corresponding to equilibrium with 1 atm. pressure of CO.

DISCUSSION

Thermodynamic Considerations

Richardson and Dennis[8] equilibrated CO–CO_2 mixtures with iron–carbon melts to study the following reaction:

$$[C] + CO_2(g) = 2CO(g) \quad \ldots\ldots(2)$$

The free-energy change of this reaction calculated from their results is

$$\Delta G_1^\circ = +34{,}500 - 31{\cdot}07T \quad \ldots\ldots(3)$$

when an infinitely dilute solution is chosen as the standard state for dissolved carbon, i.e. the activity of carbon is equal to its weight-percentage when the latter approaches zero.

The dissolution of oxygen in iron may be represented by the equation

$$\tfrac{1}{2}O_2(g) = [O] \quad \ldots\ldots(4)$$

and its free-energy change, as given by Chipman *et al.*,[9] is

$$\Delta G_2^\circ = -28{,}220 - 0{\cdot}57T \quad \ldots\ldots(5)$$

The free-energy change of the reaction

$$CO(g) + \tfrac{1}{2}O_2(g) = CO_2(g) \quad \ldots\ldots(6)$$

is obtained from the data compiled by Richardson and Jeffes,[10] i.e.

$$\Delta G_3^\circ = -67{,}500 + 20{\cdot}75T \quad \ldots\ldots(7)$$

Combination of reactions (2), (4), and (6), and equations (3), (5), and (7) yield

$$[C] + [O] = CO(g) \quad \ldots\ldots(8)$$

$$\Delta G_4^\circ = -4830 - 9{\cdot}75T \quad \ldots\ldots(9)$$

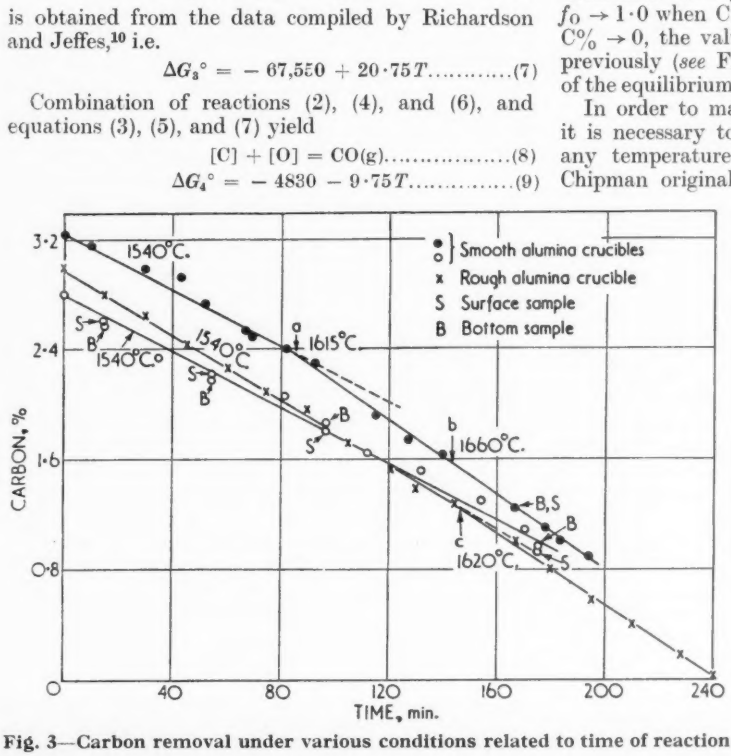

Fig. 3—Carbon removal under various conditions related to time of reaction

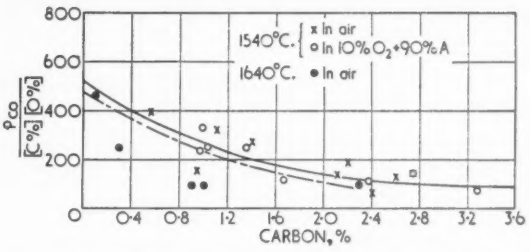

Fig. 4—Carbon–oxygen equilibrium ratio related to carbon content of molten iron at 1540° and 1640° C.; samples were taken during decarburization in air and in 10% oxygen + 90% argon mixture

and therefore,

$$\log K_4 = \frac{1056}{T} + 2{\cdot}131 \quad \ldots\ldots(10)$$

where K_4 is the equilibrium constant of reaction (8) and is given by

$$K_4 = \frac{p_{CO}}{[C\%][O\%]f_C \cdot f_O} \quad \ldots\ldots(11)$$

From the definition of the standard state, it follows that $f_C \to 1{\cdot}0$ when $C\% \to 0$. Although at low carbon concentrations the oxygen content of iron will increase, e.g., $\%[O] \simeq 0{\cdot}025$ when $\%[C] \simeq 0{\cdot}10$, its effect on carbon activity can be neglected; this assumption is justified in view of the similar tendencies observed with solutions containing, for example, silicon,[11] aluminium,[12] and chromium.[13] Furthermore, in iron–oxygen melts the activity coefficient of oxygen is unity[14] and consequently $f_O \to 1{\cdot}0$ when $C\% \to 0$. It then follows that when $C\% \to 0$, the value of the equilibrium ratio referred previously (*see* Figs. 1 and 2) approaches the value of the equilibrium constant K_4 at a given temperature.

In order to make use of equations (10) and (11), it is necessary to know the values of f_C and f_O at any temperature and composition. Marshall and Chipman originally related the activity coefficients of carbon and oxygen to the carbon content of iron; recent work[8] indicates that their results were somewhat in error. In Fig. 5, $\log f_C$, calculated from the results of Richardson and Dennis,[8] is plotted against the carbon concentration. Within the range 1560–1760°C., temperature does not affect the relationship, which may be expressed by the following linear equation:

$$\log f_C = 0{\cdot}22[C\%] \quad \ldots\ldots(12)$$

up to about 1·0% carbon.

By means of equations (10), (11), and (12), together with the curves in Figs. 1 and 2, it is possible to calculate the influence of carbon on the activity coefficient of dissolved oxygen:

Fig. 5—Effect of carbon concentration on activity coefficient of dissolved carbon, standard state being infinitely dilute solution

C, %	0·2	0·4	0·6	0·8	1·0
f_O	0·80	0·64	0·51	0·41	0·33

A plot of $\log f_O$ against the weight-percentage of carbon was found to be linear and may be represented by the following expression:

$$\log f_O = -0{\cdot}49\,[C\%] \quad \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

within the temperature range 1540–1640° C. and up to 1·0% carbon. It should be pointed out that the sum of the errors in equations (3), (5), and (7), together with the scatter of the points in Figs. 1 and 2, may give rise to about $\pm$ 25% uncertainty in the value of equation (13).

From the values calculated above and Figs. 1 and 2, the curve in Fig. 6 has been drawn for 1 atm. pressure of carbon monoxide. As indicated by equation (10), temperature has very little effect on the equilibrium constant of the carbon–oxygen reaction in iron, and in fact the curve in Fig. 6 can be used for any temperature between 1500° and 1700° C.; any error involved in this simplification is well within the usual analytical errors in oxygen determinations, as indicated by the following examples:

Temp., ° C.	1540	1640	1540	1640
C, %	0·1	0·1	1·0	1·0
O, %	0·0206	0·0221	0·0036	0·0038

It should be noted that at about 1·3% carbon the curve in Fig. 6 exhibits a minimum beyond which there is a very small increase in oxygen content with rising carbon concentration. The evidence for this is of course not very definite, but could well be due to the lowering effect of carbon on the activity coefficient of oxygen. Similar phenomena were also observed by Gokcen and Chipman[12] with the aluminium–oxygen equilibrium and by Turkdogan[13] with the chromium–oxygen equilibrium in molten iron. For comparison the following table gives the minimum concentrations of these deoxidizing elements and oxygen in molten iron in equilibrium with their respective gaseous or solid oxides at 1600° C.:

Deoxidizer	O, %	Deoxidation Product
0·04% Al	0·0008	Solid Al_2O_3
1·3% C	0·0035	1 atm. CO
4·5% Cr	0·030	Solid Cr_2O_3

It is therefore important to bear in mind that for maximum effect the addition of a deoxidizing element should be so adjusted that the concentration of the deoxidant left in solution is not more than that given by the minimum.

According to the relationship in Fig. 6, in carbon-saturated iron the oxygen content of the metal, under 1 atm. pressure of carbon monoxide, is about 0·004–0·005%.

Nucleation of Carbon Monoxide

The state of non-equilibrium of the carbon–oxygen reaction encountered in open-hearth steelmaking is now a well-known phenomenon and is associated with the conditions which control the nucleation of carbon monoxide bubbles. In their laboratory investigations, Körber and Oelsen[15] observed the effect of the crucible surface in contact with the melt. The rate of decarburization was exceedingly slow and the oxygen in solution was well above the equilibrium values when the interior of the silica crucibles were coated with a smooth layer of slag. On the other hand, the crucibles in which the melts had boiled vigorously had quite a different appearance. Their bottoms and sides were either completely or almost free from slag in those regions where the iron melt had rested.

With the present experimental melts in alumina crucibles there was no molten slag formation, and therefore the so-called ' smooth ' alumina crucibles must have had a sufficiently rough surface to nucleate gas bubbles. Nevertheless, an increase in roughness of the interior surface of the crucible increased quite definitely the rate of decarburization, as shown in Fig. 3.

It is a recognized fact that a new furnace hearth, additions to the bath of sharp-edged scrap, pig iron, etc., or a half-melted charge invariably causes a more vigorous boil. Richardson[16] and later Vallet[17] have demonstrated the importance of crevices in furnace hearths in initiating the formation of bubbles of carbon monoxide. In the absence of gas pockets, the formation of gas bubbles is very difficult, if not impossible, because the pressure of the liquid exerted on a bubble is inversely proportional to its diameter. For example, a bubble of 1 mm. dia. in molten steel is subject to a pressure of 0·06 atm. more than the liquid around it, but a bubble of 0·001 mm. dia. is subjected to an excess pressure of 61 atm. It therefore follows that to initiate the formation of a bubble, it is necessary to supersaturate the liquid with gas to a very high pressure. A simple calculation will

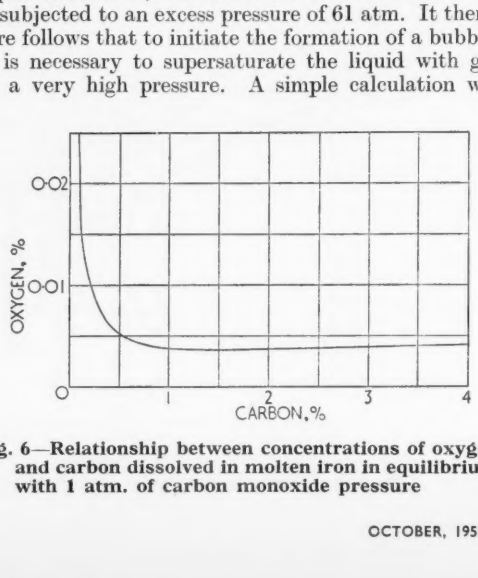

Fig. 6—Relationship between concentrations of oxygen and carbon dissolved in molten iron in equilibrium with 1 atm. of carbon monoxide pressure

show that a bubble containing a few molecules of carbon monoxide will be subject to pressures which can never be exceeded by the supersaturation of the molten iron with respect to carbon and oxygen, because both have limited solubilities. In other words, decarburization of iron under slag should never take place in the absence of crevices.

Kinetic considerations indicate that the rate of a reaction increases with an increase in the concentrations (or more correctly, activities) of the reacting species. In the case of the carbon–oxygen reaction, however, an additional physical factor has to be taken into account, i.e. nucleation of gas bubbles. Thus, the proportion of excess oxygen required for decarburization depends on the number and nature of nuclei which initiate the formation of carbon monoxide bubbles. The fact that the number of such nuclei will not be the same from melt to melt or from furnace to furnace accounts for the wide spread obtained in the relationship found in practice between carbon and oxygen contents.

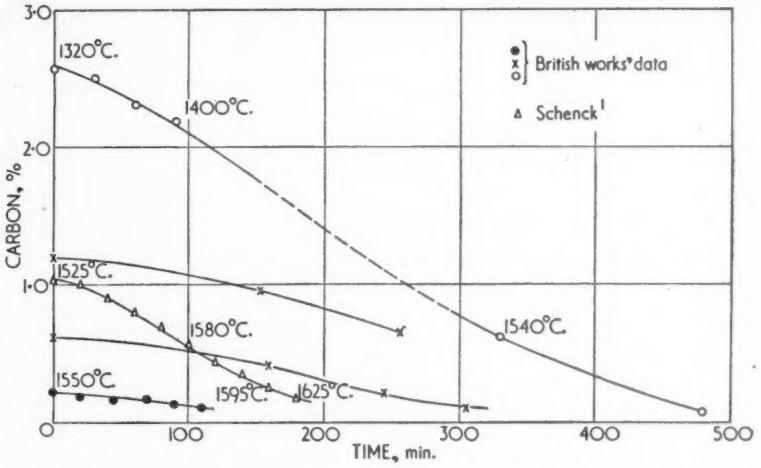

Fig. 7—Decarburization in various basic open-hearth furnaces related to time of reaction

The curves in Fig. 7 were drawn from various works' data to illustrate the manner in which the rate of decarburization can vary from one practice to another. No attempt has been made to account for the different rates. In all cases, however, the rates of decarburization are less than those obtained by the authors in melts in alumina crucibles. The excess oxygen present in these laboratory experimental melts could not be detected, indicating the easy growth of carbon monoxide bubbles and hence rapid attainment of equilibrium as indicated by Fig. 4.

A remedy for the apparently sluggish carbon–oxygen reaction in steelmaking furnaces would appear to be to inoculate the bath with gas bubbles which should readily remove carbon monoxide from the bath, resulting in rapid decarburization, as experienced in Bessemer and some oxygen-blowing processes.

The fact that the experimental melts under argon showed carbon and oxygen contents apparently in equilibrium with 1 atm. pressure of CO requires further investigation. The results may in fact be due to the mutual influence of dissolved carbon, oxygen, and aluminium or to the fact that carbon monoxide remained trapped, at approximately 1 atm. pressure, in surface crevices.[16, 17]

The sluggish carbon–oxygen reaction has also an indirect influence on the rates of some slag–metal reactions. As pointed out by Goldman, Derge, and Philbrook[18] and Turkdogan, Hancock, and Pearson,[19] the apparently slow desulphurization of pig iron by a blast-furnace slag can be increased by the additions of suitable deoxidants, e.g. aluminium, manganese, and silicon. Since the removal of sulphur from metal to slag is always accompanied by an equivalent amount of oxygen transfer in the opposite direction, the faster this oxygen is removed the faster will the desulphurization proceed.

Although in open-hearth steelmaking practice the metal is generally supersaturated with oxygen for a given carbon concentration, the oxygen content of the metal is less than that calculated from the ferrous oxide activity of the slag.[4, 5] In other words, the slag is always tending to raise the oxygen potential of the metal and the carbon is tending to lower it, with the net result that the oxygen content of the metal lies between those indicated by the slag composition and the carbon content of the iron.

When slag–metal equilibria are considered, the oxygen potential to be taken into account is that given by the ferrous oxide activity of the slag, and, as indicated elsewhere,[5, 20] according to a large number of works' data, in most open-hearth steelmaking processes the distributions of manganese, phosphorus, sulphur, and most probably silicon between slag and metal reach equilibrium values within a relatively short time of the disturbance of the bath by fresh additions or temperature changes. The state of non-equilibrium of the carbon–oxygen reaction does not seem to interfere with the equilibrium conditions of the other reactions. For instance, it was shown by Körber and Oelsen[15] that in all their carbon-bearing melts, which were supersaturated with oxygen, the distribution ratios of silicon and manganese between the metal and slag were the same as those obtained in carbon-free melts of otherwise the same composition.

CONCLUSIONS

For the reaction

$$[C] + [O] = CO(g)$$

the equilibrium constant is given by:

$$\log K = \frac{1056}{T} + 2{\cdot}131$$

where

$$K = \frac{p_{CO}}{[C\%][C\%]f_C \cdot f_O}$$

The activity coefficients of carbon and oxygen, f_C and f_O, are related to the carbon content of the metal, thus

$$\log f(C) = 0{\cdot}22[C\%]$$
$$\log f(O) = -0{\cdot}49[C\%]$$

up to 1·0% carbon and at any temperature encountered under steelmaking conditions.

The equilibrium carbon–oxygen relationship at 1 atm. pressure of carbon monoxide is shown graphically; this relationship is almost independent of temperature as indicated by the expression for the equilibrium constant.

The rate of decarburization appears to be affected by the surface condition of the crucible in contact with the melt. As shown by previous workers, if the container is coated with a smooth layer of slag, the melt becomes supersaturated with carbon and oxygen. In the presence of sufficient nuclei to initiate the formation of carbon monoxide bubbles, the excess oxygen required to maintain the oxidation process is exceedingly small and cannot be detected by analysis. Under such favourable circumstances, the carbon and oxygen contents remain at equilibrium values even though the carbon content is changing.

Open-hearth practice, however, does not apparently offer the required nuclei, and consequently, the rate of decarburization in such furnaces is slow even in the presence of high excess oxygen.

Acknowledgment

The authors wish to express their thanks to Dr. J. Pearson for many useful discussions.

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Metallography of Delta-Ferrite

Part II—FORMATION OF DELTA-EUTECTOID IN 18–4–1-TYPE HIGH-SPEED STEELS

By Kehsin Kuo

SYNOPSIS

The overheating, burning, and solidification of high-speed steels of the 18–4–1 type have been correlated with the formation of δ-ferrite and its subsequent decomposition into austenite and the Fe_3W_3C carbide, with special stress on the effects of the carbon content and of the rate of cooling on the formation of this aggregate (δ-eutectoid).

The ternary peritectic reaction

liquid + δ-ferrite → austenite + carbide

was generally prevented from proceeding to completion in ordinary steel ingots during solidification, and instead of this reaction, the following two binary eutectic and eutectoid reactions occurred: liquid → austenite + carbide, and δ-ferrite → austenite + carbide.

1103

THE PRESENCE OF δ-ferrite in tungsten high-speed steels was first considered by Grossmann and Bain[1] in connection with the overheating phenomenon, and later by Murakami and Hatta[2] in connection with the solidification process. Though a troostite-like dark-etching constituent has frequently been encountered in decarburized[1, 3] and low-carbon[1, 2, 4] high-speed steels, it has not been suggested, except for the recent note of Nehrenberg and Chow,[5] that this constituent is a *direct* decomposition product of δ-ferrite. This constituent is very often considered as the pearlite formed on cooling from an austenite with low carbon content. In overheated steels, this low-carbon austenite exists in the decarburized surface layers.[1] In steel ingots, it exists in the austenite formed at higher temperatures[2] by the binary peritectic reaction, $l(\text{liquid}) + \delta \rightarrow \gamma$. Hultgren[6] has further elaborated this point by suggesting that the δ-ferrite in overheated high-speed steels has lower carbon and manganese contents and higher silicon, chromium,

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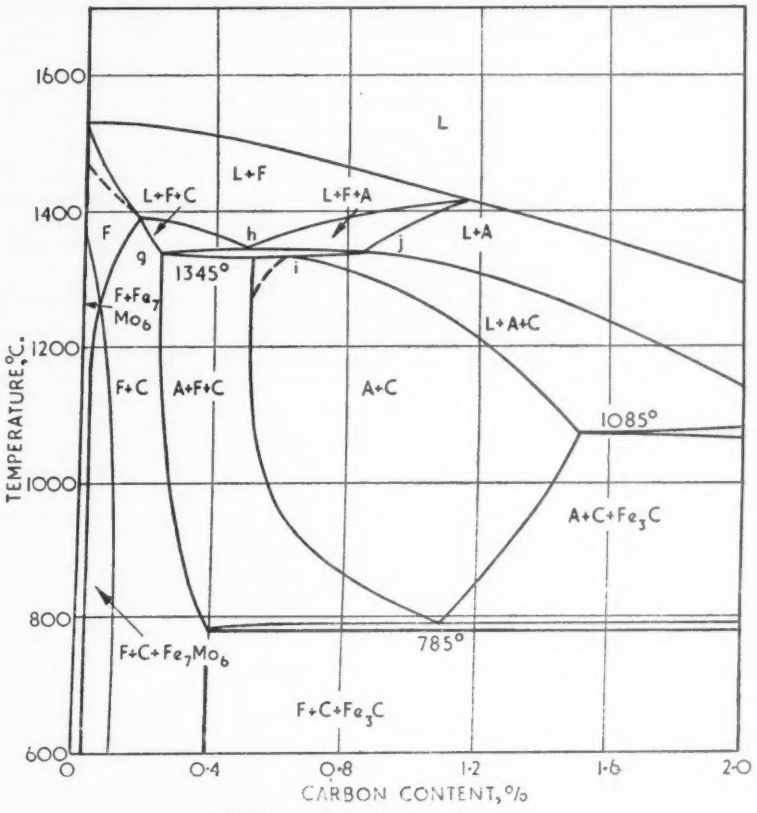
Mr. Kuo is at the Department of Metallography, Royal Institute of Technology, Stockholm, Sweden.

and tungsten contents than the austenite with which the ferrite is in equilibrium. Consequently, the austenite formed from this ferrite on rapid cooling will have a lower carbon content than the rest.

The eutectoid decomposition of δ-ferrite in a high-molybdenum steel has been discussed in Part I of this series of papers.[7] The high-temperature ferrite decomposes at lower temperatures into an aggregate of austenite and an alloy carbide with the typical appearance of pearlite, and this aggregate is called δ-eutectoid. From the similarity of tungsten and molybdenum as an alloy element in steels, such a reaction is also to be expected in high-tungsten steels. The product of this reaction will be a eutectoid of austenite plus the Fe_3W_3C carbide.

The overheating, burning (partial melting), and solidification of the 18–4–1 (W–Cr–V)-type high-speed steels were studied with respect to the formation of δ-ferrite and its subsequent decomposition into δ-eutectoid. Special attention has been paid to the effects of the steel composition and of the rate of cooling on the formation of this aggregate.



L: liquid; *A*: austenite; *F*: ferrite; *C*: Fe_3W_3C

Fig. 1—Constitutional diagram of Fe–W–Cr–C system: section at 18% W and 4% Cr (after Murakami and Hatta,[2] with alterations indicated by dotted lines)

CONSTITUTION OF 18–4–1-TYPE HIGH-SPEED STEEL

The chemical composition of this type of steel points to a very complicated system which contains no less than five components. Since the contents of chromium and vanadium are not very high and their behaviours are similar to those of tungsten, this complicated system can perhaps be considered as a slightly modified Fe–W–C system. Hultgren[6] and Mitchie[8] have used the section diagram at 20% W of the ternary system Fe–W–C to discuss the phase changes in the 18–4–1-type high-speed steels.

Based upon Takeda's work on Fe–W–C alloys,[9] Murakami and Hatta[2] studied the constitution diagram of the section at 18% W and 4% Cr of the quaternary system Fe–W–Cr–C. The range of carbon content investigated by them is from 0·2 to 1·0%. They maintained that the addition of 4% of chromium will not introduce any new phase into the Fe–W–C system and that a part of the chromium is dissolved in the matrix and the rest in the carbide. In other words, the constitution diagram is qualitatively the same as that of Fe–W–C alloys without chromium. Nevertheless, the ternary peritectic, eutectic, and peritectoid reactions in this quaternary system will no longer take place at fixed temperatures, and three four-phase regions, though very narrow, appear in the diagram (Fig. 1).

This diagram is reproduced, with two alterations indicated by the dotted lines, from the original work of Murakami and Hatta.[2] Since the melt of an Fe–W–Cr alloy with 18% W and 4% Cr will not solidify at a constant temperature but through a temperature interval, the $L + F$ two-phase region will also exist in this alloy. Furthermore, the boundary between the $A + C$ two-phase and the $A + F + C$ three-phase regions has also been modified because of the following reasons. Firstly, as will be shown shortly, δ-ferrite can appear at high temperatures without incipient fusion in alloys which contain only austenite and carbide at low temperatures. This is only possible if this boundary has the shape indicated by the dotted line. Secondly, according to Takeda's diagram for Fe–W–C alloys with 18% of tungsten,[9] the point *i* in Fig. 1 lies at a higher carbon content than the point *h*. The addition of 4% of chromium is not likely to change this relationship to any noticeable extent.

Strictly speaking, Fig. 1 is theoretically incorrect. Since the publication of Takeda's work on the Fe–W–C system, a new double carbide of iron and tungsten, $Fe_{21}W_2C_6$ or $M_{23}C_6$, has been found.[10] In comparison with M_6C, $M_{23}C_6$ occurs in steels with a

lower tungsten content[11] and dissolves in the steel matrix at a lower temperature.[12] For this reason the $M_{23}C_6$ carbide should also appear in Fig. 1, in the region of high carbon content and low temperature. Furthermore, the addition of chromium will not only enlarge the steel composition range within which $M_{23}C_6$ appears, owing to the formation of an isomorphous carbide $Cr_{23}C_6$, but will also introduce the Cr_7C_3 carbide into tungsten high-speed steels.[13] However, in these steels the $M_{23}C_6$ and Cr_7C_3 carbides are not stable at temperatures above 1100° C., and M_6C remains as the only undissolved carbide. In other words, Fig. 1 can still be used as a guide in dealing with high-temperature phase-changes, which are the main interests of the present paper.

High-speed steels in general also contain 1–2% of vanadium. The effect of vanadium on the Fe–C diagram is quite similar to that of chromium and tungsten, though the former is more effective in the formation of alloy carbide (*see* Part V). A part of the carbon will thus be removed from the steel matrix as undissolved VC carbide particles. For this reason, when vanadium is added into 18–4 W–Cr steels the points *g*, *h*, *i*, and *j* in Fig. 1 will move towards higher carbon contents. Apart from this, no other complication may be expected.

EXPERIMENTAL METHODS

The compositions of the steels used in this investigation are as follows:

Steel	C,%	W,%	Cr,%	V,%
M	0·67	18·3	3·90	1·35
N	0·73	18·1	4·22	1·51

These two steels were chosen because the first one has a composition corresponding to an Fe–W–Cr–C alloy lying between points *h* and *i* and the second one an alloy lying between points *i* and *j* in Fig. 1. At 1300° C., both steels contain austenite and the Fe_3W_3C carbide; but on further heating to a temperature below the four-phase region *ghijg*, δ-ferrite appears in the steel *M* and liquid appears in the steel *N*.

The size of the steel specimen was generally 3 × 3 × 3 mm., so that efficient heating and cooling can be achieved. Melting studies were made in an evacuated Tammann furnace and other high-temperature heat treatments were carried out in purified nitrogen in a Silit furnace.

Steel specimens were polished first with diamond dust which gives a rather even surface without any relief of the hard VC particles. The faint scratches left by the diamond dust polish can be entirely removed by a second polish with fine alumina powder. However, after this second polish both the VC and Fe_3W_3C carbide particles stood out in relief, as shown in Fig. 2. This picture was taken from a burnt high-speed steel with 0·93% C, 7·9% W, 2·00% Mo, 4·12% Cr, and 2·13% V in order to show the two kinds of eutectic; one consists of austenite plus VC, and the other of austenite plus Fe_3W_3C. Because of its great hardness, VC can easily be differentiated from Fe_3W_3C. These two kinds of eutectic occur also in the two steels used in the present investigation, although the amount of VC-eutectic is comparatively small. The VC pattern in Fig. 2 is a typical example of quenched steels. After slow cooling, VC appears as isolated particles.

The etchant used was 6% nital and the etching time was 5–10 min. In general, this etchant gives quite satisfactory results, but it attacks only slightly the martensitic matrix. In certain cases, the etchant recommended by Amberg (HCl 20 ml., C_2H_5OH 65 ml., H_2O 15 ml., $CuCl_2$ 1 g.) was used to bring out the structure of martensite.[14]

The microhardness measurement was made with a Hanemann microhardness tester; the load used was 25 g.

RESULTS AND DISCUSSIONS

With the aim of dissolving as much of the alloy elements and carbon in the matrix as possible, high-speed steels are generally quenched from a temperature about 30–40° C. below the solidus. Notwithstanding the precise temperature control, overheating (austenite grain growth and formation of δ-ferrite) and burning (partial melting) cannot always be avoided. Though the microstructure of overheated and burnt high-speed steels has been frequently published,[15, 16] the mechanism of these reactions still remains unknown. To achieve a better understanding of these phenomena, high-speed steels have been heated to various temperatures within the range 1280–1500° C., followed by different rates of cooling. The results of the microscopic studies are presented below according to the heating temperature.

Below 1325° C.

Takeda[9] found that in the Fe–W–C system the peritectic reaction $l + \delta \rightarrow \gamma + Fe_3W_3C$ occurs at 1335° C. In the Fe–W–Cr–C system this reaction occurs[2] within a narrow temperature range around 1345° C. According to Ôya,[17] the peritectic reaction $l + \delta \rightarrow \gamma + VC$ in the Fe–V–C system occurs at 1330° C. Below 1325° C., no peritectic reaction will be expected.

Steel M—The change in structure of steel *M* with a quenching temperature up to 1325° C. is shown in Figs. 3–6. The normal structure, Fig. 3, represents a steel quenched from 1280° C. in oil and consists of polygons of austenite with undissolved M_6C carbides. The function of these massive M_6C carbides in suppressing the austenite grain growth is quite obvious, as evidenced by the carbide particles at the grain boundaries.

After having been quenched from 1310° C. the M_6C carbide (proved by X-rays) lost its irregular spherical shape and became angular.[18] This gives the impression that at this stage M_6C has taken up its cubic crystal form; the different appearance in the two-dimensional section depends upon the different orientations of the M_6C carbide.

At 1320° C. carbide particles began to melt along the austenite grain boundaries (Fig. 4). The dark-etching constituent at the grain boundary is irregular in shape, whilst those within the grain are angular and sometimes, in the same grain, are of the same shape and orientation.[19] This feature can best be seen in high-carbon tungsten or molybdenum high-speed steels. Figure 5 represents a steel with 0·85% C, 7·0% W, 4·09% Mo, 4·2% Cr, and 2·16% V, which has been heated to 1310° C.

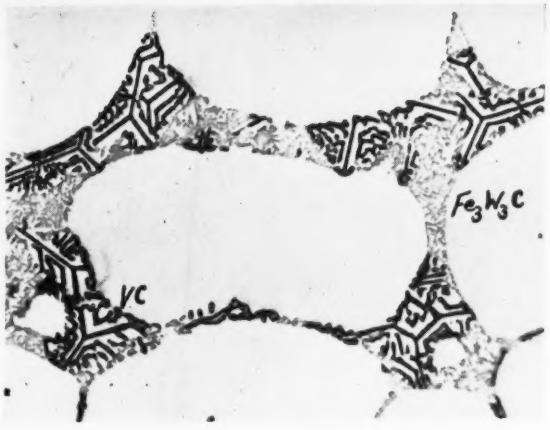


Fig. 2—Steel 1951 (0·93% C, 7·9% W, 2·00% Mo, 4·12% Cr, 2·13% V): 1300° C., oil. Polished but not etched. VC and M_6C-eutectics. × 1000

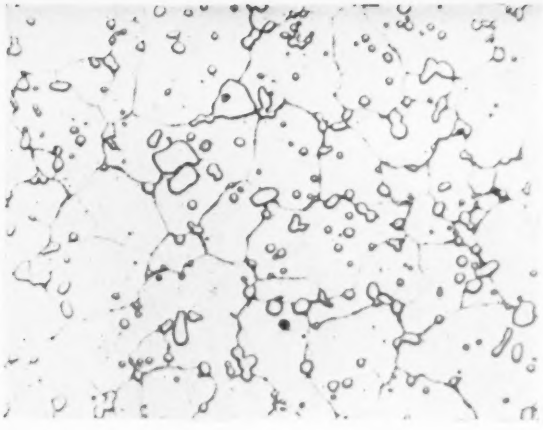


Fig. 3—Steel *M*: 1280° C., oil. Normal structure; undissolved carbide—M_6C. × 1000

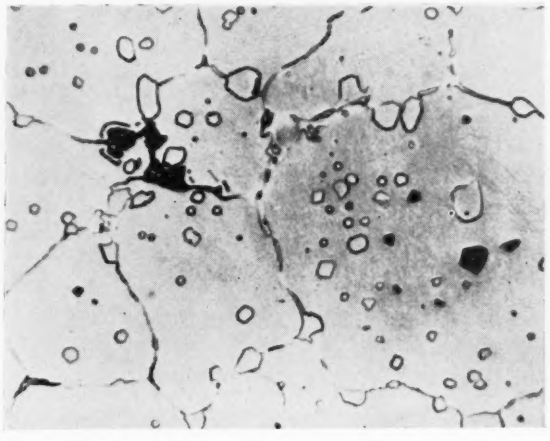


Fig. 4—Steel *M*: 1320° C., oil. Overheated structure, angular and irregular dark-etching constituents × 1000

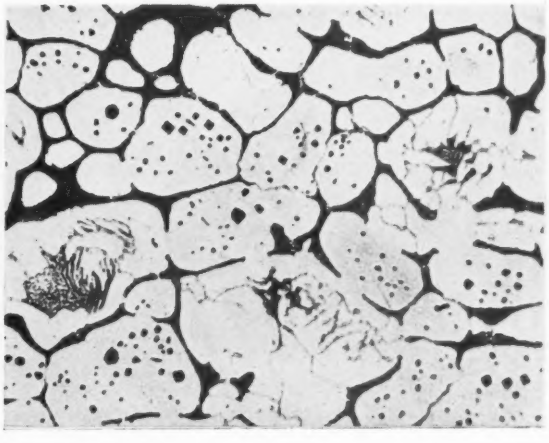


Fig. 5—Molybdenum steel (0·85% C, 7·0% W, 4·09% Mo, 4·2% Cr, 2·16% V): 1310° C., oil. Angular dark-etching constituent of similar shape and orientation × 300

(a) (b)

Fig. 6—Steel *M*: dark-etching constituent is transformation product of δ-ferrite (× 1000):
(*a*) 1325° C., oil. Complete transformation;
(*b*) 1325° C., brine. Incomplete transformation

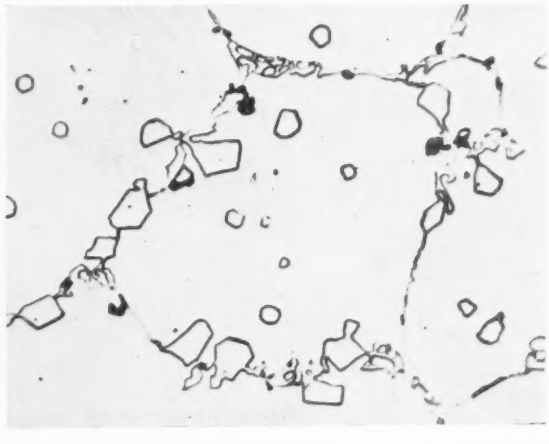
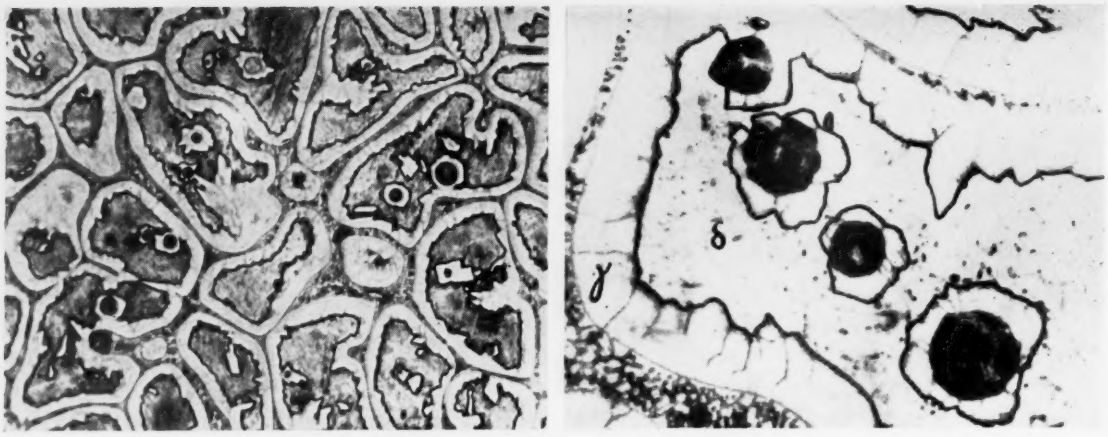


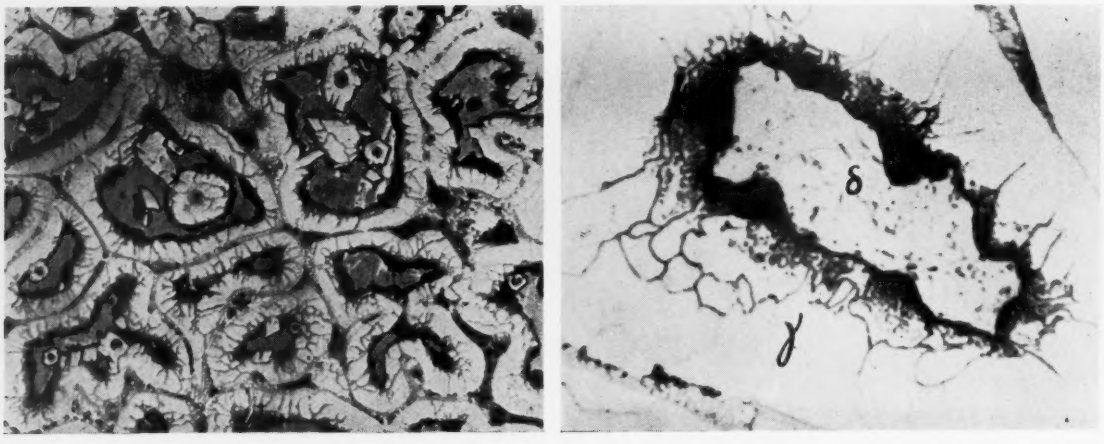
Fig. 7—Steel *N*: 1325° C., oil. Partial melting × 1000

Figs. 3–7: etched in 6% nital



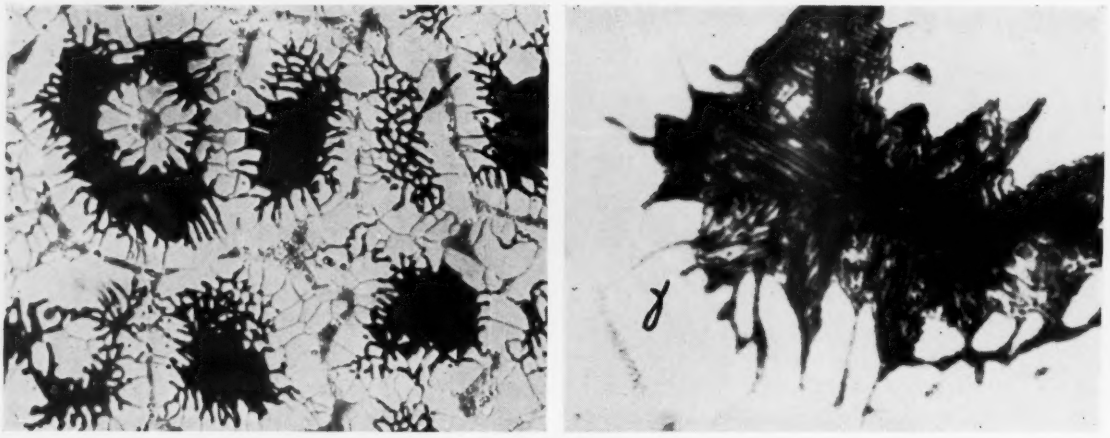
(a) × 300 (b) × 2000

Fig. 8—Steel *M*: 1350° C., water. Austenite formed on cooling at liquid/δ-ferrite interface



(a) × 300 (b) × 2000

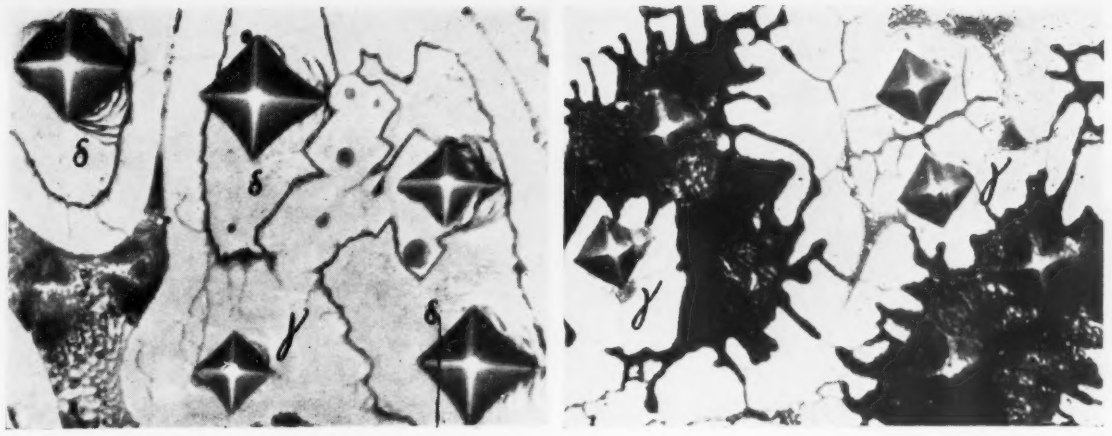
Fig. 9—Steel *M*: 1350° C., oil. Formation of δ-eutectoid at transformation front



(a) × 300 (b) × 2000

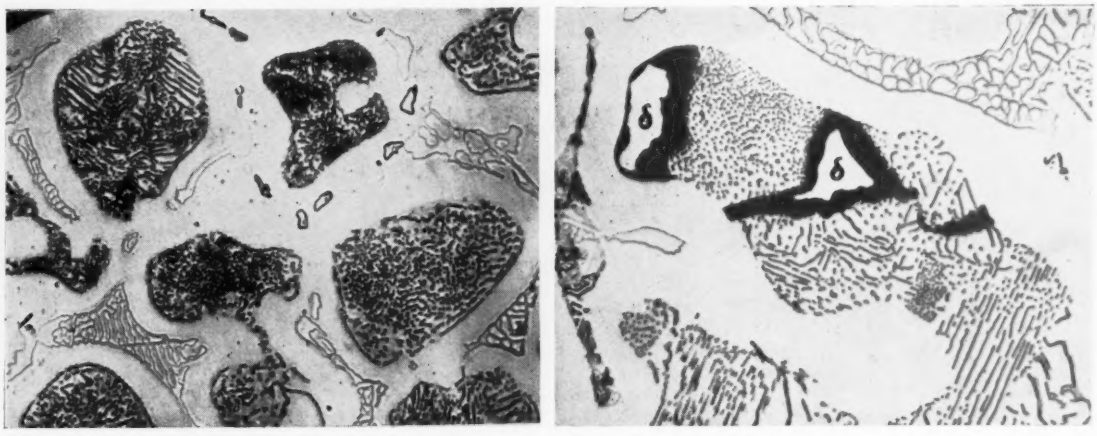
Fig. 10—Steel *M*: 1350° C., air cooling. δ-Ferrite completely transformed; lamellar δ-eutectoid

Figs. 8–10: etched in 6% nital



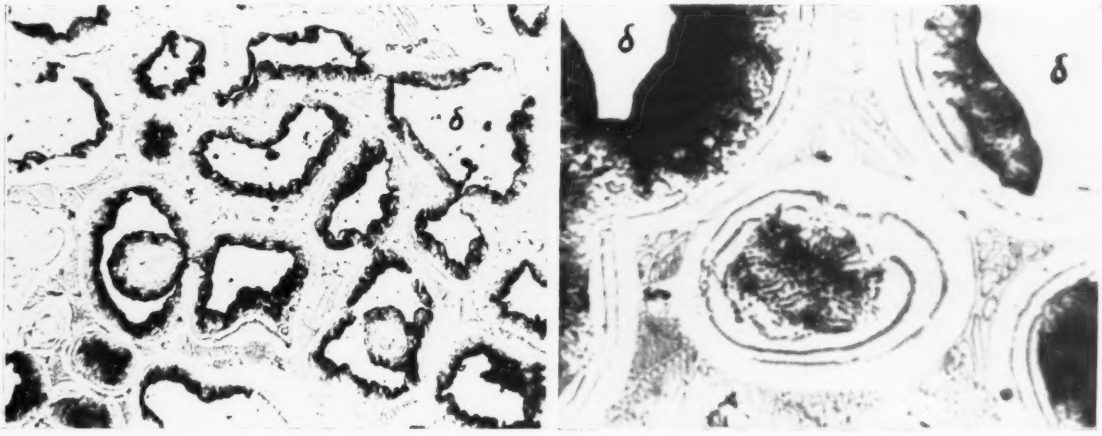
(a) (b)

Fig. 11—Microhardness measurements on steel *M* (× 1200): (*a*) 1350° C., water. δ-Ferrite: $H = 370$; martensite (austenite): $H = 927$; (*b*) 1350° C., air cooling. δ-Eutectoid: $H =$ approx. 870



(a) (b)

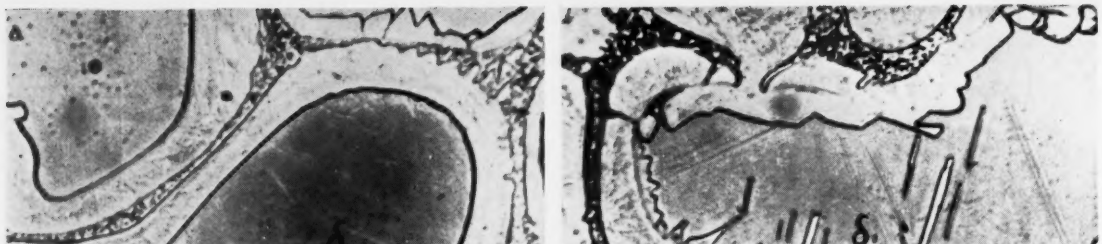
Fig. 12—Steel *M*: 1350° C., furnace cooling: (*a*) to 1280° C., water. Ledeburite and δ-eutectoid (× 500); (*b*) to 1315° C., water. Incomplete transformation of δ-ferrite (× 1000)



(a) × 300 (b) × 2000

Fig. 13—Steel *M*: 1350° C., stepwise cooled. Carbide rings

Figs. 11–13: etched in 6% nital



(a) (b)

Fig. 14—Steel *N*: 1350° C., water (× 1200): (*a*) surface region; smooth austenite band existed at 1350° C.; (*b*) interior; austenite rods formed during quenching; etched in Amberg's reagent

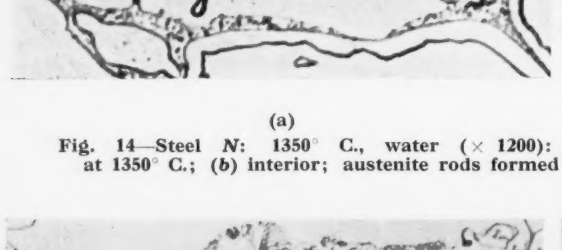


Fig. 15—Steel *N*: 1350° C., oil. Carbide precipitation at old δ/γ interface × 1200

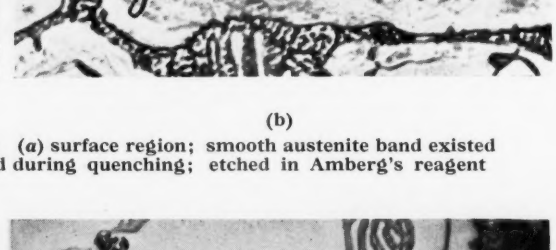


Fig. 16—Steel *N*: 1350° C., air cooling. Carbide precipitation at austenite grain boundaries (shown by arrows) and δ-eutectoid colonies × 1200

Fig. 17—Steel *M*: 1500° C.. water. δ-Ferrite dendrites × 2000

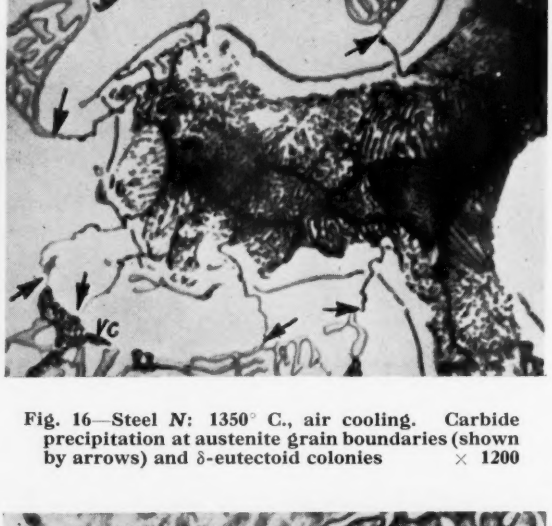


Fig. 18—Steel *M*: 1500° C., furnace cooled to 1200° C., water. Martensitic (austenitic) matrix of δ-eutectoid. Etched in Amberg's reagent × 1500

Figs. 14*a* and 15–17: etched in 6% nital

Figure 6*a* is of a steel specimen which has been quenched from 1325° C. in oil; the dark-etching constituent appears at the junctions of austenite grains and occupies the old sites of δ-ferrite, the boundary of which is marked out by a carbide border.[19] Austenite islands, usually with massive carbide particles within them, are frequently observed in this dark-etching constituent. Bain[20] considered these austenite islands as high-carbon regions (caused by the solution of carbide) which have not been transformed into δ-ferrite. In other words, a carbon concentration gradient exists in austenite from the carbide/austenite interface to the austenite/ferrite interface.

That the site of this dark-etching constituent has been occupied by δ-ferrite can be seen from Fig. 6*b*, prepared from a water-quenched specimen. In this case, the decomposition of δ-ferrite is partially suppressed by the rapid cooling. The angular dark-etching constituent observed in the austenite grain, as shown in Figs. 4 and 5, is believed to be formed by the same mechanism.

Since the formation of δ-ferrite can take place without incipient fusion, the composition of steel *M* must be such that on heating it passes from the $A + C$ two-phase into the $A + F + C$ three-phase region. The assumption made earlier concerning the boundary between these two regions in Fig. 1 is thus proved to be correct. As already mentioned, it is the common opinion that this high-temperature ferrite transforms on cooling to a low-carbon austenite, which on further cooling decomposes into some kind of pearlite, depending upon the rate of cooling. The formation of δ-ferrite and its subsequent decomposition will be discussed shortly.

Steel N—Figure 7 represents the structure of the steel *N* quenched from 1325° C. No δ-ferrite or dark-etching constituent can be found, though partial melting has already begun at the grain boundaries. This indicates that the composition of this steel lies somewhere between the points *i* and *j* in Fig. 1, so that on heating this steel is brought from the $A + C$ two-phase into the $L + A + C$ three-phase region.

Comparing Figs. 6*a* and 7, the effect of the carbon content on the structure of overheated and burnt high-speed steels is thus made clear. The effect of *M*, where *M* is tungsten, chromium, or vanadium, in modifying the constitution diagram of Fe–*M*–C is in the reverse direction to that of carbon and much less effective (*see* Part V). Therefore, at a certain carbon level, δ-ferrite will be found in a high-speed steel with a higher alloy content and partial melting will be found in a steel with a lower alloy content. In such high-alloy steels as high-speed steels, segregation of alloy elements cannot be avoided. In severe cases, both types of structure shown in Figs. 6*a* and 7 may appear in different parts of the same steel specimen. This is believed to be caused by the segregation of alloy elements rather than that of carbon, which has a high diffusion rate at such high temperatures. However, if the steel specimen is not well protected from decarburization during high-temperature heat treatments, the dark-etching constituent will always be present in the surface regions of the steel.

Grobe and Roberts[4] also found the presence of this dark-etching constituent in 18–4–1-type high-speed steels with low carbon contents (e.g. 0·52%) but not in steels with high carbon contents (0·67–0·78%) after having been quenched from 1290° C.

1350° C.

Before going into the details of the microscopic examination, it is perhaps useful to examine the relationship between the composition of the steels and the phase-changes during heating and cooling according to Fig. 1.

Since the steel *M* at 1350° C. has a composition between *h* and *i* and very close to *h*, this steel contains possibly only liquid and δ-ferrite. On cooling, austenite will be formed first by the binary peritectic reaction $l + \delta \rightarrow \gamma$, and later together with the Fe_3W_3C carbide by the ternary peritectic reaction $l + \delta \rightarrow \gamma + Fe_3W_3C$. If the equilibrium state prevails, all the liquid will be consumed by the latter reaction, and the steel will be brought into the $A + F + C$ three-phase region. In this case, the eutectic reaction $l \rightarrow \gamma + Fe_3W_3C$ will be absent.

On further cooling δ-ferrite will disappear and this steel will enter into the $A + C$ two-phase region. The decomposition of δ-ferrite in alloy steels has already been discussed in Part I.[7] In recapitulation: since δ-ferrite contains more tungsten (and other ferrite-formers like chromium and vanadium) than austenite, the disappearance of δ-ferrite on cooling will not only produce austenite but also the Fe_3W_3C carbide. Owing to the extremely high rate of diffusion of carbon at such high temperatures, the supply of carbon can easily be maintained for the continuous formation of the Fe_3W_3C carbide during the decomposition of δ-ferrite. However, the diffusion of tungsten is slow and the formation of Fe_3W_3C eventually stops. Meanwhile, suffering from the loss of the ferrite-former tungsten, the δ-ferrite in contact with the Fe_3W_3C carbide will transform into an austenite with a lower tungsten content. This will cause an accumulation of tungsten in the surrounding ferrite and will provide possibilities for the formation of new carbide particles. This process will repeat itself and an aggregate of austenite and the Fe_3W_3C carbide will thus form from δ-ferrite in a eutectoid manner ($\delta \rightarrow \gamma + Fe_3W_3C$) resembling that of pearlite, and this aggregate is called δ-eutectoid. However, the controlling factor in the present case is the diffusion of tungsten in the ferrite, and note that the coefficient of diffusion of tungsten in ferrite at 1330° C. is of the order of $10{\cdot}0 \times 10^{-8}$ sq. cm./sec.,[21–23] a figure very close to that of carbon in austenite at 700° C., which is $3{\cdot}5 \times 10^{-9}$ sq. cm./sec.[24]

Owing to the higher carbon content of steel *N*, at 1350° C. some austenite is left to exist together with the liquid and δ-ferrite. On slow cooling to a temperature below the line *gij*, δ-ferrite will be completely consumed by the same ternary peritectic reaction discussed above. On further cooling, the remaining liquid will decompose eutectically ($l \rightarrow \gamma + Fe_3W_3C$) into austenite and carbide which is generally called ledeburite. In this case the eutectoid reaction $\delta \rightarrow \gamma + Fe_3W_3C$ will be absent.

According to Fig. 1, at 1200° C. both steels will contain austenite and carbide; if the cooling rate is extremely slow so that the equilibrium state can be attained, the structure in these two steels will be quite different. There will be no ledeburite in steel *M* and no δ-eutectoid in steel *N*. Since the peritectic reaction is a time-consuming process it seldom proceeds to completion. (It is time consuming because the reaction products will separate the reactants so that the reactants lose direct contact with each other, and further reaction can only take place by diffusion through the reaction products.) The liquid is not completely consumed in steel *M* nor is δ-ferrite completely consumed in steel *N*. Both the ledeburite and the δ-eutectoid will be formed in these two steels according to the following two reactions:

$$l \rightarrow \gamma + Fe_3W_3C$$
$$\delta \rightarrow \gamma + Fe_3W_3C$$

The products of these two reactions are the same but their appearances are quite different.

Steel M—In order to study the decomposition of δ-ferrite on cooling, specimens of steel *M* were heated to 1350° C. for 3 min. and the behaviour noted at various rates of cooling. At 1350° C. this steel is supposed to contain only the liquid and δ-ferrite.

Figure 8 illustrates the result of quenching in brine. Melting started in the form of nodules within the grain and of envelopes to enclose the grain, and the structure of these chilled liquid drops within the grain is not resolved even at a magnification of 2000 (Fig. 8*b*). Notwithstanding this drastic cooling, austenite was growing from the δ/l interface into δ-ferrite which, however, was to a great extent retained. No δ-eutectoid could be found, and the markings in austenite were probably the grain boundaries of the growing austenite.

Oil quenching is shown in Fig. 9. In this case the formation of austenite was succeeded by that of δ-eutectoid, the structure of which resembles either sorbite or troostite (Fig. 9*b*), depending upon the temperature of formation. Some δ-ferrite was retained, and a general precipitation of carbide in it also occurred.

Figure 10 illustrates air cooling. Austenite grew in the form of rods from the δ/l interface inwards into the δ-ferrite, as shown in Fig. 10*a*. The section was made at the top of the grain marked with an arrow, and the austenite rods, cutting perpendicularly, appeared as islands. The δ-eutectoid formed at higher temperatures is resolved as being a pearlite-like aggregate of austenite and the Fe_3W_3C carbide (Fig. 10*b*). Note that the austenite rods and the pearlite- and troostite-like δ-eutectoids are all transformation products of δ-ferrite, but formed at successive lower temperatures on cooling. The fact that no δ-ferrite is left after air cooling shows the extremely high rate of decomposition of δ-ferrite in the 18–4–1-type high-speed steel.

Microhardness measurements were made on martensite (old austenite), δ-ferrite, and δ-eutectoid. Figure 11*a* was taken from the same specimen as Fig. 8, i.e. one quenched in brine. The δ-ferrite had a diamond pyramid hardness of 370 (kg./sq. mm.), whilst the martensite had the same hardness as a hardened high-speed steel: D.P.N. 927 (Rockwell *C* 66).* Figure 11*b* was taken from the air-cooled specimen. The pearlite-like δ-eutectoid had a hardness (D.P.N. 870) very close to that of martensite. The possibility that the matrix of this eutectoid is anything other than martensite (austenite) was thus excluded. The hardness of this δ-eutectoid was somewhat lower than the austenite rods, probably because the austenite of the former has a lower carbon content as a consequence of the formation of Fe_3W_3C.

Figure 12 illustrates furnace cooling. By switching off the current the steel was cooled in the furnace from 1350° to 1280° C. in 3 min., and was followed by quenching in water. The structure is shown in Fig. 12*a*, which clearly indicates that on slow cooling the liquid decomposes into a eutectic (ledeburite) and the δ-ferrite into a eutectoid (δ-eutectoid).

The austenite band between the ledeburite and δ-eutectoid was probably the transformation product of the binary peritectic reaction between the liquid and the δ-ferrite, $l + \delta \rightarrow \gamma$. This austenite band differs from the austenite rods in air-cooled and quenched steels not only in appearance but also in the formation mechanism, since the austenite in the air-cooled and quenched steels was formed directly from the super-cooled δ-ferrite. Note that there is no grain boundary in this austenite band.

If the furnace cooling is arrested at 1315° C., untransformed liquid (fine eutectic near the left edge of Fig. 12*b*) and δ-ferrite are left. The troostite-like structure separating the δ-ferrite and δ-eutectoid is probably the fine δ-eutectoid formed at low temperatures on quenching from 1315° C.

By furnace cooling the δ-eutectoid was made to have such an open structure that the matrix is clearly martensite (austenite at high temperatures); this is evident from Figs. 12 and 18. This reaction was also proved to be a true eutectoid decomposition of δ-ferrite, not a combination of the formation of austenite followed by the precipitation of carbide in it. The coarse δ-eutectoid in this case was formed above 1280° C.

Stepwise cooling is shown in Fig. 13. Steel specimens were removed in steps of 2 cm. from the middle part of the tube furnace so that the temperature of the specimen dropped in a stepwise manner; this was followed by quenching in water. Since untransformed δ-ferrite is still present, the temperature at which quenching took place was above 1280° C. Following the stepwise fall of temperature, δ-ferrite was retreating from the δ/l interface inwards in a corresponding manner, leaving carbide rings to mark out its old boundaries. The eutectoid decomposition of δ-ferrite took place during continuous cooling as shown by the increase in the degree of fineness of the δ-eutectoid. Most of the δ-ferrite was retained by quenching. The similarity of the δ-eutectoid in Figs. 6 and 13*b* should be noticed. The carbide border surrounding the δ-eutectoid that is generally observed in overheated high-speed steels was proved to be the

* The ferrite hardness is, however, misleading because the area of ferrite is small in comparison with that of the indentation, so that the contribution from the surrounding martensite cannot be neglected. Actually, the hardness of ferrite is less than that reported here.

old boundary of δ-ferrite, which provided favourable sites for the precipitation of carbide, as suggested earlier by Hultgren.[19] A similar phenomenon has been observed by Cina[25] in a high-alloy valve steel *XCR* (0·45% C, 24% Cr, 5% Ni, and 2·5% Mo).

Steel N—The decomposition of δ-ferrite in this steel has been studied in a manner similar to that in steel *M*; at 1350° C. steel *N* contains not only the liquid and δ-ferrite, but also austenite.

Quenching in brine is shown in Fig. 14. In Fig. 14*a* the smooth contour of the δ-ferrite/austenite boundary indicates that no new austenite has been formed from δ-ferrite on cooling and the austenite band is that already existing at 1350° C. In other words, the state at 1350° C. was retained by this rapid cooling. However, this microstructure is taken from the surface region of the steel specimen, and in the interior of the steel specimen austenite rods formed on cooling are also found to be present (Fig. 14*b*). There was no carbide precipitation to mark out the old γ/δ interface, and this boundary is brought out by using Amberg's etchant. Another point of interest is the absence of grain boundary in this austenite band; this, however, is an exception rather than a general phenomenon.

Figure 15 illustrates quenching in oil. The carbide ring marked out the old boundary of δ-ferrite, which on cooling partly transformed into austenite and later into δ-eutectoid; part of the δ-ferrite was retained.

In air cooling, Fig. 16, the grain boundaries of the austenite existing at 1350° C. were now occupied by carbide and they were generally connected with the carbide ' arms ' of the ledeburite. Since the austenite existed already at 1350° C. and the ledeburite was formed afterwards on cooling from this temperature, it is perhaps reasonable to suggest that the formation of this carbide eutectic occurs more easily, even if it is not nucleated at these sites. On cooling, these austenite grains grew into δ-ferrite and were later followed by the formation of δ-eutectoid. In spite of this rapid cooling serrated carbide precipitation occurred along the austenite grain boundaries and the old δ/γ interface.

Furnace cooling presented no new features other than that there was more austenite and less δ-eutectoid formed from δ-ferrite than in steel *M*. Theoretically if the rate of cooling is slow, δ-ferrite will be consumed by the binary peritectic reaction $l + \delta \rightarrow \gamma + Fe_3W_3C$ and no δ-eutectoid will be formed at all in this steel.

From these descriptions the marked influence of the rate of cooling on the appearance of the decomposition products of δ-ferrite is made clear. It is not unusual that in large steel specimens several of the structures described may appear in the same specimen owing to the different rates of cooling in the exterior and interior regions.

The statement made previously concerning the effect of segregation of alloy elements and carbon on the structure of high-speed steels heated to 1325° C. can also apply here, although the difference of burnt structure in these two steels, at least at the cooling rates used in the present investigation, is not material. However, as the cooling rate is further reduced, the effect of segregation will be more obvious.

1500° C.

Cooling from 1500° C. presented no structure that has not been found in steels cooled from 1350° C. Some experiments were included in this work to shed some light on the solidification process of the 18–4–1-type high-speed steels.

The microstructure of high-speed steel ingot has been satisfactorily illustrated by Grossmann and Bain[1] and therefore no description of the ingot structure will be given here.

At 1500° C. steel *M* was in the liquid state. A small drop of this melt was poured into a 10% NaOH solution and it solidified in a few seconds. The dendritic pattern of the δ-ferrite, partially transformed into austenite and δ-eutectoid, is shown in Fig. 17. Except for the small size of these ferrite dendrites, the structure is similar to that shown in Fig. 9 and no further explanation of the decomposition of δ-ferrite is necessary.

Figure 18 represents the structure of this steel cooled in a Tammann furnace from 1500° C. to about 1200° C. in 15 min. and then rapidly cooled. By means of Amberg's etchant not only was the matrix shown to be martensitic (austenitic), but the difference in composition of the peritectic and eutectoid austenites was also brought out. Otherwise, this micrograph is quite like Fig. 12*a*.

From the fact that heating to 1500° or 1350° C. gives the same constitution, it can be concluded that during solidification δ-ferrite forms primarily from the liquid in dendritic form until the temperature passes 1350° C., then solid transformation in δ-ferrite begins to occur together with the eutectic decomposition of the remaining liquid. The mode of this solid transformation, as described earlier, is governed by the rate of cooling. In the interior of large ingots where very slow cooling occurs, the binary and ternary peritectic reactions between liquid and δ-ferrite may take place. Actually, this is rarely the case, at least for the ternary peritectic reaction. The most common ingot structure is a mixture of coarse ledeburite and δ-eutectoid, separated by an austenite band formed by the binary peritectic reaction. The appearance of the δ-eutectoid varies between the pearlite-like and troostite-like structures resulting from different cooling rates, depending upon its location in the ingot.

GENERAL DISCUSSION

Most of the experimental work on the eutectoid decomposition of δ-ferrite described was made by heating the steel to a temperature above the ternary peritectic reaction $l + \delta \rightleftharpoons \gamma + Fe_3W_3C$. In fact, the presence of liquid is not a necessary condition for the formation of δ-eutectoid in low-carbon high-speed steels. The series of microstructures shown in Figs. 3–6 indicates that δ-ferrite begins to appear in steel *M* at 1320° C., i.e. on heating to this temperature this steel was brought from the two-phase region $A + C$ into the three-phase region $A + F + C$. On cooling, it was once more brought into the two-phase region $A + C$, and δ-ferrite disappeared by the eutectoid reaction $\delta \rightarrow \gamma + Fe_3W_3C$. In high-carbon high-speed steels, δ-ferrite can only be produced by the ternary peritectic reaction $\gamma + Fe_3W_3C \rightarrow l + \delta$; but the

eutectoid decomposition of δ-ferrite, in spite of the presence of the melt, still remains the same.

The eutectoid reaction of δ-ferrite dealt with here is not exactly analogous to that presented before in Part I.[7] In the latter case, the high-molybdenum steel on cooling was brought from the $A + F$ two-phase region into the $A + F + C$ three-phase region. Together they represent two of the seven possible variations of the same reaction, which will be discussed together with the constitution diagrams of the Fe–M–C systems in Part V.

The steels used in the present work belong to the most common type (18–4–1) of high-speed steels. Since the dark-etching constituent (δ-eutectoid) has also been found in other types of high-speed steel,[15, 16] e.g. 6–5–4–2 and 1–9–4–1 W–Mo–Cr–V types, the structural changes and their mechanisms discussed above can just as well apply to these other types.

CONCLUSIONS

(1) The 18–4–1 type of high-speed steel consists of austenite and carbide (Fe_3W_3C) at 1300° C. On further heating, δ-ferrite appears first in low-carbon, and liquid first in high-carbon steels. On cooling, δ-ferrite decomposes into a troostite-like eutectoid of austenite plus carbide, which is often called the dark-etching constituent. On slow cooling, this dark-etching constituent appears, like the pearlite, with carbide lamellæ in it.

(2) This constituent can also form in high-carbon high-speed steels if the steel has been heated to a temperature above the four-phase peritectic reaction $\gamma + Fe_3W_3C \rightarrow l + \delta$.

(3) During solidification δ-ferrite dendrites form primarily from the melt and later decompose first by the binary peritectic reaction $l + \delta \rightarrow \gamma$ and later by the ternary peritectic reaction $l + \delta \rightarrow \gamma + Fe_3W_3C$. Since these peritectic reactions are time-consuming processes, in ordinary cooling conditions they seldom proceed to completion. Instead the following two eutectic and eutectoid reactions occur: $l \rightarrow \gamma + Fe_3W_3C$ and $\delta \rightarrow \gamma + Fe_3W_3C$.

(4) Similar reactions are believed to occur also in other types of high-speed steel.

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Part III—ISOTHERMAL TRANSFORMATION OF DELTA-FERRITE IN A LOW-CARBON 27–5–1·5 Cr–Ni–Mo CORROSION-RESISTANT STEEL

By Kehsin Kuo

SYNOPSIS

At 1250° C. a low-carbon 27–5–1·5 Cr–Ni–Mo steel contains only ferrite, which decomposes partially at lower temperatures into an aggregate of austenite and carbide. This aggregate has the typical appearance of lamellar pearlite when formed above 900° C. and of acicular bainite when formed below 700° C. Between 700° and 900° C., both types of structure are observed. The isothermal transformation diagram of this ferrite also resembles that of austenite in a hypo-eutectoid carbon steel. 1102

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THE EUTECTOID DECOMPOSITION of δ-ferrite into an aggregate of austenite and carbide in high-alloy steels has been discussed in previous papers.[1, 2] This aggregate, or δ-eutectoid, resembles the pearlite not only in its appearance but also in its mechanism of formation, with the carbide as the nucleating phase. It has also been suggested[1] that an acicular aggregate of austenite and carbide nucleated by austenite, analogous to bainite, may form from δ-ferrite within

a temperature range somewhat lower than that of δ-eutectoid. Though theoretically possible, the occurrence of such an acicular aggregate in straight high Mo or Cr steels is hindered in practice by the fact that the austenite becomes unstable as the transformation temperature is lowered.

Nickel is known to promote the formation of austenite and, if this already exists, to stabilize it. For this reason, a low-carbon 27–5–1·5 Cr–Ni–Mo steel was chosen to study the isothermal transformation of δ-ferrite, with special interest in the formation of a bainite-like transformation product. Nehrenberg and Lillys[3] have already shown that lamellar δ-eutectoid can form in a steel with 0·24% C and 24·85% Cr. These authors also mentioned that this lamellar δ-eutectoid has been found in a Ni–Cr stainless steel (*AISI* 329) of similar nominal analysis to the steel used in the present investigation.

STRUCTURAL CHANGES ACCOMPANYING HEATING AND COOLING

The steel used in this investigation was supplied as 20 × 20 sq. mm. bars by Sandvikens Jernverk from their stock, and its percentage composition is the following:

C	Si	Mn	Cr	Ni	Mo
0·079	0·39	0·43	25·9	5·3	1·44

This steel has a ferrite–austenite duplex structure in the delivered state and is known to have excellent corrosion-resistant properties at low temperatures. At high temperatures, the formation of sigma phase in ferrite makes it extremely brittle.[4] It was developed in Sweden mainly for use in the pulp industry.

Figure 2 shows the structure of this steel after having been heated for 1 hr. at 1050° C., and this contained austenite (white), ferrite (grey), and the $Cr_{23}C_6$ carbide (black). The etchant was modified Murakami's reagent with 10 g. $K_3Fe(CN)_6$, 10 g. KOH, and 40 g. H_2O, which attacks $Cr_{23}C_6$ and sigma severely, ferrite slightly, and austenite not at all.[5] This reagent also stains the phases differently (carbide, black; sigma, orange-brown; ferrite, grey; austenite, colourless) so that they can easily be identified in high-chromium steels. Murakami's reagent should be freshly prepared and used hot, with an etching time of about 5–10 sec.

Owing to the relatively high magnification Fig. 2 does not reproduce the proportion of these phases correctly; the amount of austenite in this steel specimen was actually only about 20–25%.

At 1150° C. carbide was completely dissolved and the amount of austenite was slightly reduced (Fig. 3). Moreover, austenite appeared as separated blocks instead of parallel bands along the rolling direction. The ferrite grain size was about A.S.T.M. No. 2.

Above 1150° C. the amount of austenite decreased rapidly with temperature and at 1200° C. this steel became entirely ferritic. Figure 4 represents the structure of a steel specimen quenched from 1250° C. in 10% NaOH. Despite this drastic quenching, some kind of precipitation occurred at the grain boundaries and within the ferrite grains. Veining marked by the precipitate also appeared in ferrite. The etchant used was Vilella's reagent (5% HCl + 2% picric acid), which attacks austenite most, ferrite slightly, and

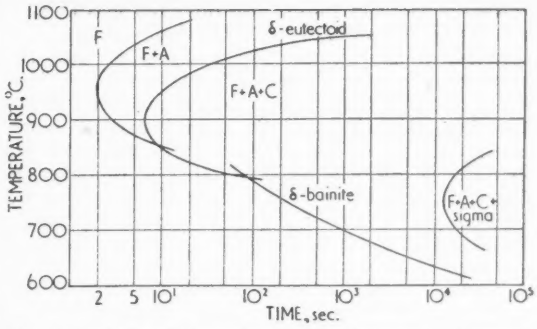


Fig. 1—Isothermal transformation diagram (1% transformation)

carbide least.[6] This fact makes it possible, by using oblique illumination (Fig. 4*b*), to identify the minute particles in ferrite as austenite, although they otherwise rather resemble carbide particles. There is another reason to believe this to be the case, because the precipitate did not appear after the complete solution of carbide (Fig. 3), but only after the complete solution of austenite (Fig. 4). The ferrite grain size increased materially in the absence of austenite bands or blocks: the average area of a ferrite grain after 10 min. at 1250° C. was about 1 sq. mm., corresponding to A.S.T.M. No. — 3.

During air cooling from 1250° C. the precipitation of austenite proceeded first as parallel rods along certain planes and later at lower temperatures in the form of general precipitation of small particles (Fig. 5*a*). In this photomicrograph, the austenite rods are sectioned longitudinally in the upper grain and transversely in the lower one. Note that there exists a certain orientation relationship between these two sets of crystallographic planes in which the precipitation of austenite rods takes place, and that when these two groups of austenite rods join at the ferrite grain boundary, no discontinuity in austenite can be detected. This gives the impression that austenite rods begin to form at the grain boundary and grow along nearly opposite directions into these two ferrite grains.

The migration of ferrite grain boundary shown in Fig. 5*a* is also of interest. It seems that those points along the phase boundary marked with arrows, at which a sharp change in direction of the austenite rods occurs, are the site of the original boundary before migration. If a line is drawn to connect these points, a smooth boundary will result.

Figure 5*b* shows the growth of austenite rods along a certain crystallographic plane across the horizontal ferrite grain boundary, which was also partly distorted and now is occupied by austenite.

Comparing the smooth grain boundary in Fig. 4*a*, it is evident that the migration shown in Fig. 5 is caused by the precipitation of austenite rods. It is not yet possible to ascertain the mechanism of this kind of boundary migration, although it has been noticed that in Fig. 5 the new boundary is in general perpendicular, or nearly so, to the newly formed austenite rods. By this, the δ/δ phase boundary is shortened and the interfacial energy is reduced.

Nehrenberg and Lillys[3] also observed this kind of veining and grain-boundary migration in the 25% Cr steel mentioned above. They suggested that the veining is caused by the hot deformation arising from the volume change which accompanies the $\delta \rightarrow \gamma$ transformation, and that the grain-boundary migration is the result of variable rate of growth of austenite in different directions. Since veining is absent in Fig. 5, in which the growth of austenite has proceeded farther than in Fig. 4*a*, it may be concluded that the formation of austenite is possibly not the reason for the appearance of veining. The rapid contraction of ferrite on drastic cooling may cause enough deformation in itself to cause veining to appear. In this connection veining was not observed in a steel specimen quenched from 1250° C. in oil.

ISOTHERMAL TRANSFORMATION OF DELTA-FERRITE

Transformation Diagram

Steel specimens were heated for 10 min. at 1250° C. to obtain a completely ferritic structure and were then brought into a salt or lead bath, depending upon whether the transformation temperature is above or below 850° C. Isothermal transformation of δ-ferrite has been studied from 1100° down to 600° C. at 50° C. intervals. The amount of transformation was estimated visually and the isothermal transformation characteristics are shown in Fig. 1.

The fact that austenite precipitation in ferrite cannot be suppressed by drastic quenching makes the determination of this diagram difficult and inaccurate, and Fig. 1 can only be accepted as approximate illustrating the general feature of transformation. All these single *C*-curves denote approx. 1% transformation. The non-ferritic transformation products (austenite, carbide, and sigma), even after long holding time, never amount to more than 50%. This is because ferrite is a stable constituent in this steel from its melting point down to room temperature and therefore complete transformation of δ-ferrite can never be attained.

This transformation diagram resembles that of austenite in a hypo-eutectoid carbon steel in two respects: firstly, there is a single *C*-curve for the pro-eutectoid transformation product, and secondly, the *C*-curve for δ-eutectoid joins that for the low-temperature acicular transformation product at about 800° C. in such a way that they appear to form a continuous *C*-curve. To differentiate the two different transformation mechanisms and products, Hultgren[8] has generally found two *C*-curves for the formation of pearlite and bainite, respectively; the curve is here arbitrarily broken off at about 800° C. Austenite, not associated with carbide, also formed abundantly below 850° C., although this occurred at a later stage and is not drawn in the diagram. After long holding, the FeCr sigma phase, with some molybdenum dissolved in it, began to appear and this also had a single *C*-curve.

The austenite–carbide aggregate, formed above 900° C., resembled a lamellar pearlite and that formed below 700° C. resembled an acicular bainite. Between 700° and 900° C. both types of structure were observed. In the following, the structural changes at 1000°, 800°, and 700° C. will be shown to illustrate the different transformation products.

At 1000° C.

At this temperature the transformation of δ-ferrite started with the formation ot pro-eutectoid austenite, followed by that of δ-eutectoid.

Figure 6*a* shows austenite rods, very often with δ-ferrite islands within them, formed after 1 hr. at 1000° C. In Fig. 6*b* a group of parallel, sometimes hollow, austenite rods arranged along particular parallel crystallographic planes is sectioned transversely. As stated earlier, after heating to 1250° C. the ferrite grain size was very large and this is probably the reason why the Widmanstätten arrangement of austenite is always very obvious in this steel (*see* also Figs. 8*b*, 10*a*, and 14*a*).

From Fig. 7*a* it can be seen that austenite forms first and δ-eutectoid later from the δ/γ interface into ferrite. Those δ-eutectoid units just starting to form are marked with arrows and the one in the middle-lower part of Fig. 7*a* deserves special mention. The formation of this eutectoid unit seems to begin with the precipitation of a carbide plate, followed by the formation of austenite surrounding it. In appearance, this rather resembles a graphite flake with an austenite sheath. Figure 7*b* also illustrates this feature. These photomicrographs may serve as further confirmation of the statement made earlier[1] that δ-eutectoid is nucleated by an alloy carbide, in this case $Cr_{23}C_6$, and that the governing factor is the diffusion of this alloy element in ferrite.

Owing to the limited amount of available carbon (the total amount of carbon in this steel is 0·079%), the formation of δ-eutectoid soon stopped.

At 800° C.

Figure 1 shows that at 800° C. the formation of δ-eutectoid leads the transformation. This often started from the chromite ($FeO.Cr_2O_3$) inclusions (Fig. 8*a*) or from the grain boundaries (marked with arrows in Fig. 8*b*). (Because of the low magnification, the contrast in tone between γ (white) and δ-eutectoid (grey) in Fig. 8*b* is not very obvious.) The formation of troostite-like nodules starting from an inclusion is a well-known fact.[8] Figure 8*b* also shows that austenite rods, arranged in a Widmanstätten pattern, form at this temperature at a later stage.

δ-Eutectoid can also form in ferrite without the help of any kind of interface, such as δ/δ, δ/γ, and $\delta/FeO.Cr_2O_3$ (Fig. 9*a*). These δ-eutectoid units are more or less like troostite nodules and their structure becomes coarser during growth. The details of the fine eutectoid structure are shown in the electron micrograph, Fig. 9*b*, where carbide appears as light and austenite as dark areas. Since Vilella's reagent attacks austenite, the replica in contact with austenite is fairly thick and thus reduces the intensity of the electron beam such that austenite becomes dark in appearance. The replica technique used was that developed by Modin.[9]

At 800° C. an acicular aggregate of austenite and carbide resembling a bainite unit also appeared along the grain boundaries (Fig. 10*a*) and in the interior (Fig. 10*b*) of δ-ferrite.

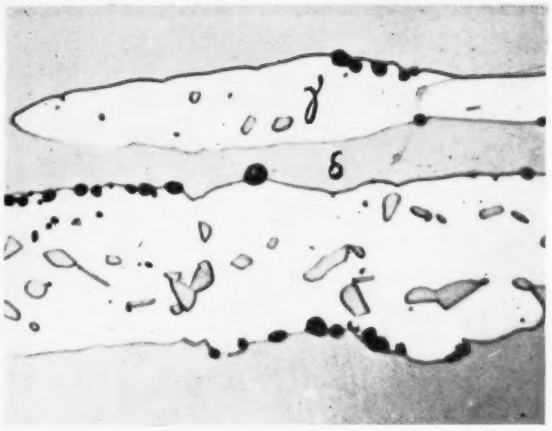
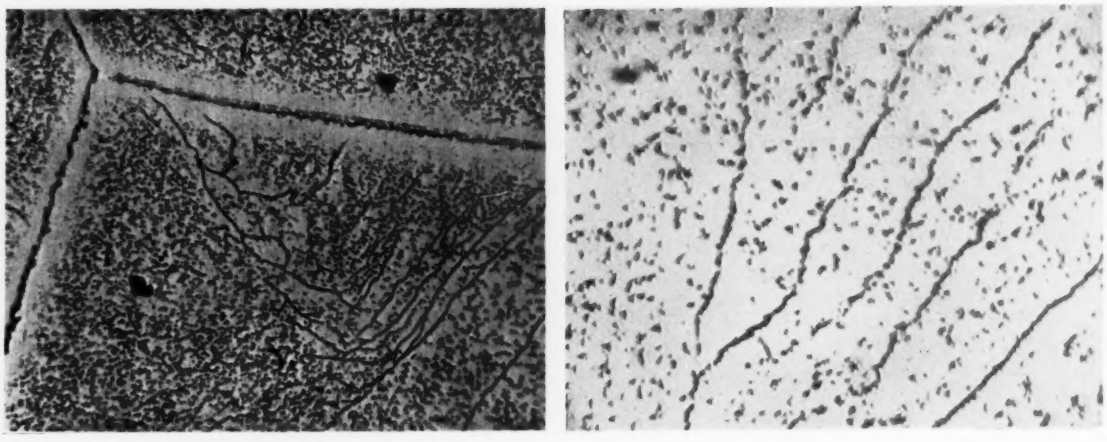


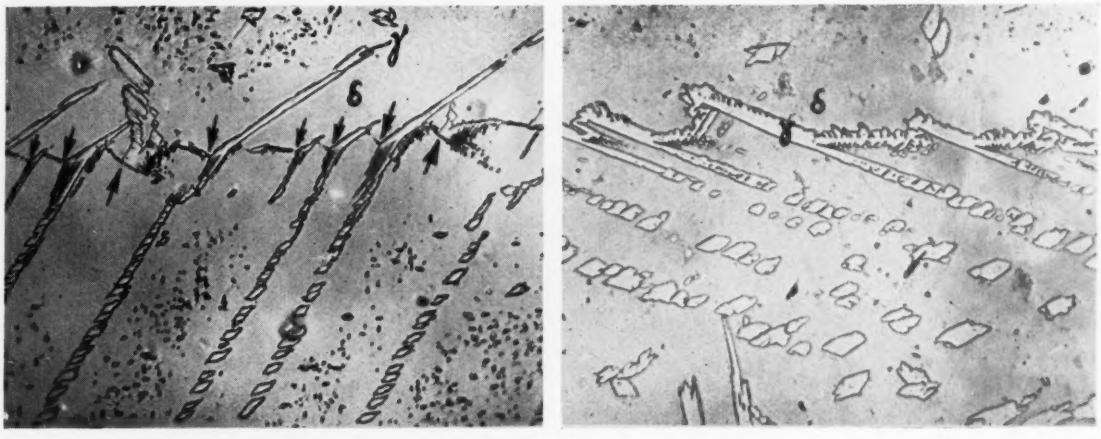
Fig. 2—Microstructure at 1050° C., 1 hr., W.Q. Austenite bands with δ-ferrite islands in them and carbide particles at δ/γ interface × 1200

Fig. 3—Microstructure at 1150° C., 30 min., W.Q. Austenite blocks in ferrite × 400



(a) × 400 (b) Oblique (→) illumination : × 2000

Fig. 4—Precipitation of austenite and veining in ferrite : 1250°C., 10 min., W.Q.



(a) (b)

Fig. 5—Precipitation of austenite rods in certain parallel crystallographic planes and grain boundary migration in ferrite: 1250° C., 10 min., air cooling (× 400): (*a*) arrows show original boundary; (*b*) growth of austenite rod across grain boundary

Etchant : Murakami's reagent (Figs. 2, 3, 5), Vilella's reagent (Fig. 4)

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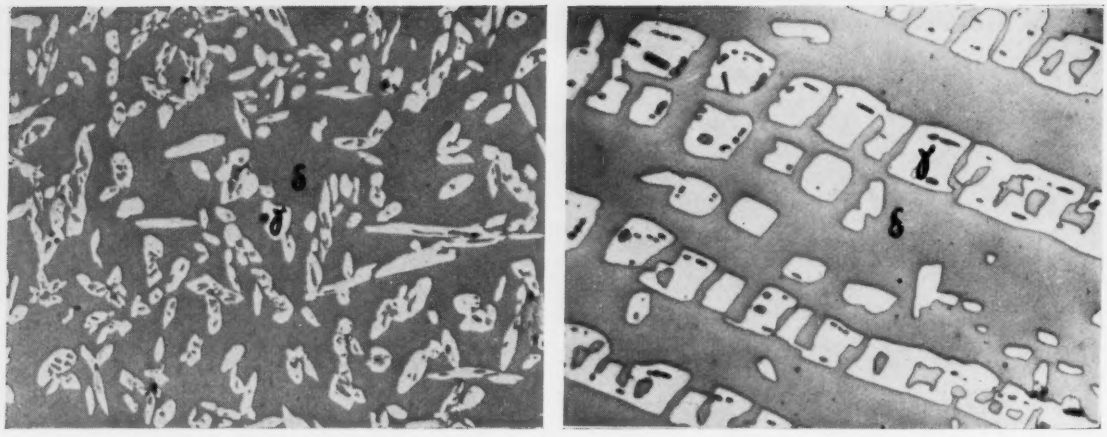
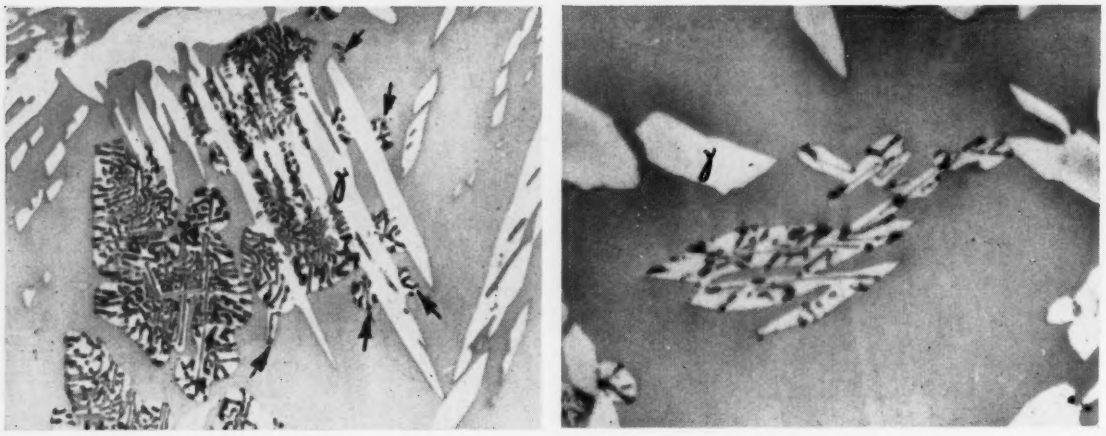


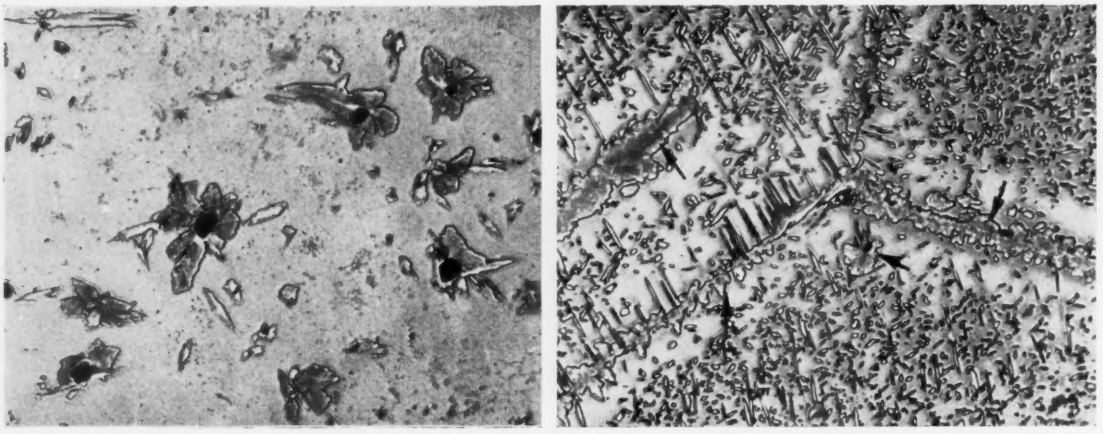
(a) (b)

Fig. 6—Formation of pro-eutectoid austenite at 1000° C., 1 hr., W.Q.: (*a*) acicular austenite rods with δ-ferrite islands (× 400); (*b*) austenite rods in Widmanstätten arrangement (× 1200)



(a) (b)

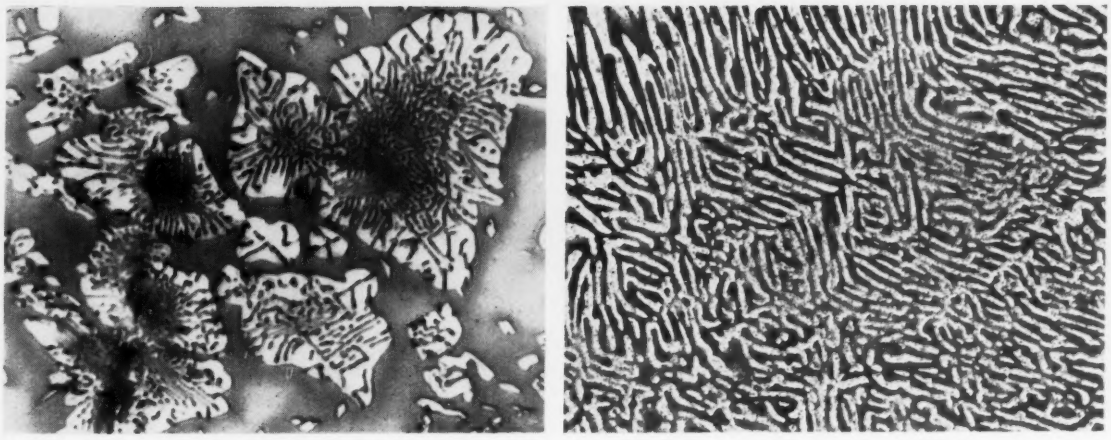
Fig. 7—Formation of δ-eutectoid at 1000° C., 2 min., W.Q.: (*a*) δ-eutectoid grows from austenite rods which formed earlier; arrows show early stage of δ-eutectoid formation (× 1200); (*b*) carbide plate with austenite sheath (× 2000)



(a) (b)

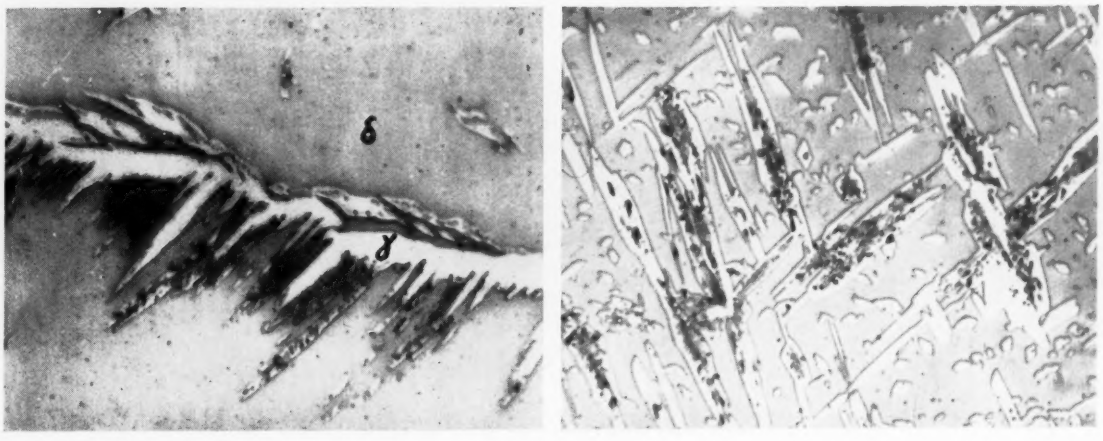
Fig. 8—Isothermal transformation at 800° C. (× 400): (*a*) 10 min., W.Q.; δ-eutectoid nodules grow from chromite inclusions; (*b*) 1 hr., W.Q.; formation of austenite in Widmanstätten patterns in three ferrite grains; arrows show δ-eutectoid

Figs. 6-8 : etched in Murakami's reagent



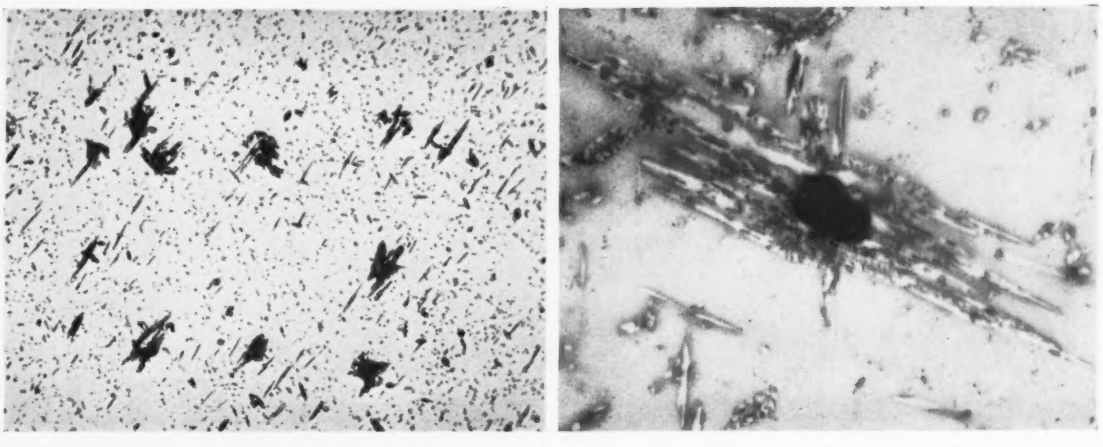
(a) (b)

Fig. 9—δ-Eutectoid formed at 800° C., 10 min., W.Q.: (*a*) δ-eutectoid grows coarser (× 2000); (*b*) electron photomicrograph (× 10,000)



(a) (b)

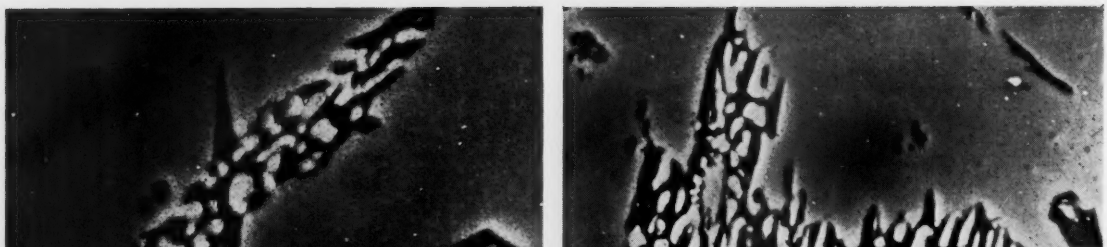
Fig. 10—Acicular aggregate of austenite and carbide formed at 800° C.: (*a*) 10 min., W.Q.; grain boundary aggregate (× 2000); (*b*) 1 hr., W.Q.; acicular aggregates and smaller austenite rods of same orientations in Widmanstätten arrangement (× 1200)



(a) (b)

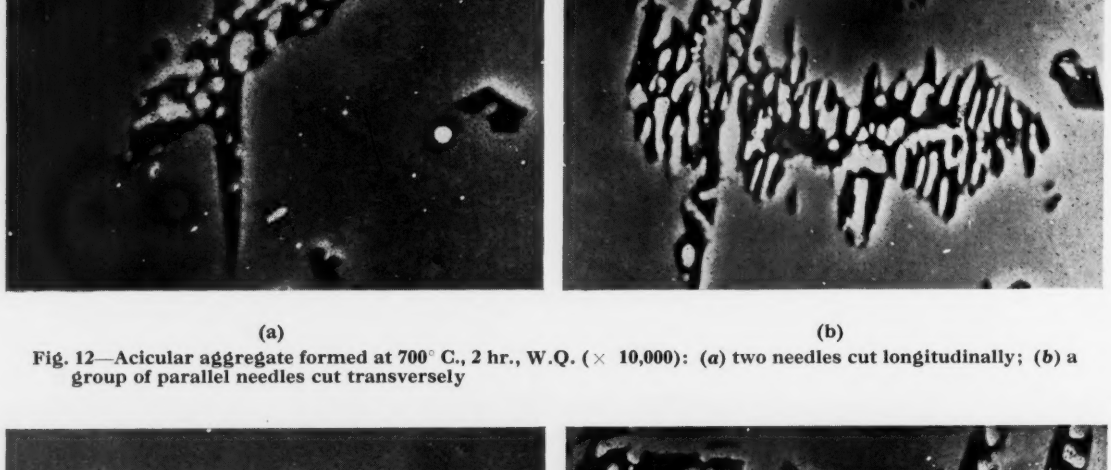
Fig. 11—Acicular aggregate formed at 700° C.: (*a*) 2 hr., W.Q.; acicular aggregate grows from chromite inclusion (× 400); (*b*) 5 hr., W.Q.; a group of parallel acicular aggregates (× 2000)

Etchant: Murakami's reagent (Figs. 9*a*, 10, 11), Vilella's reagent (Fig. 9*b*)



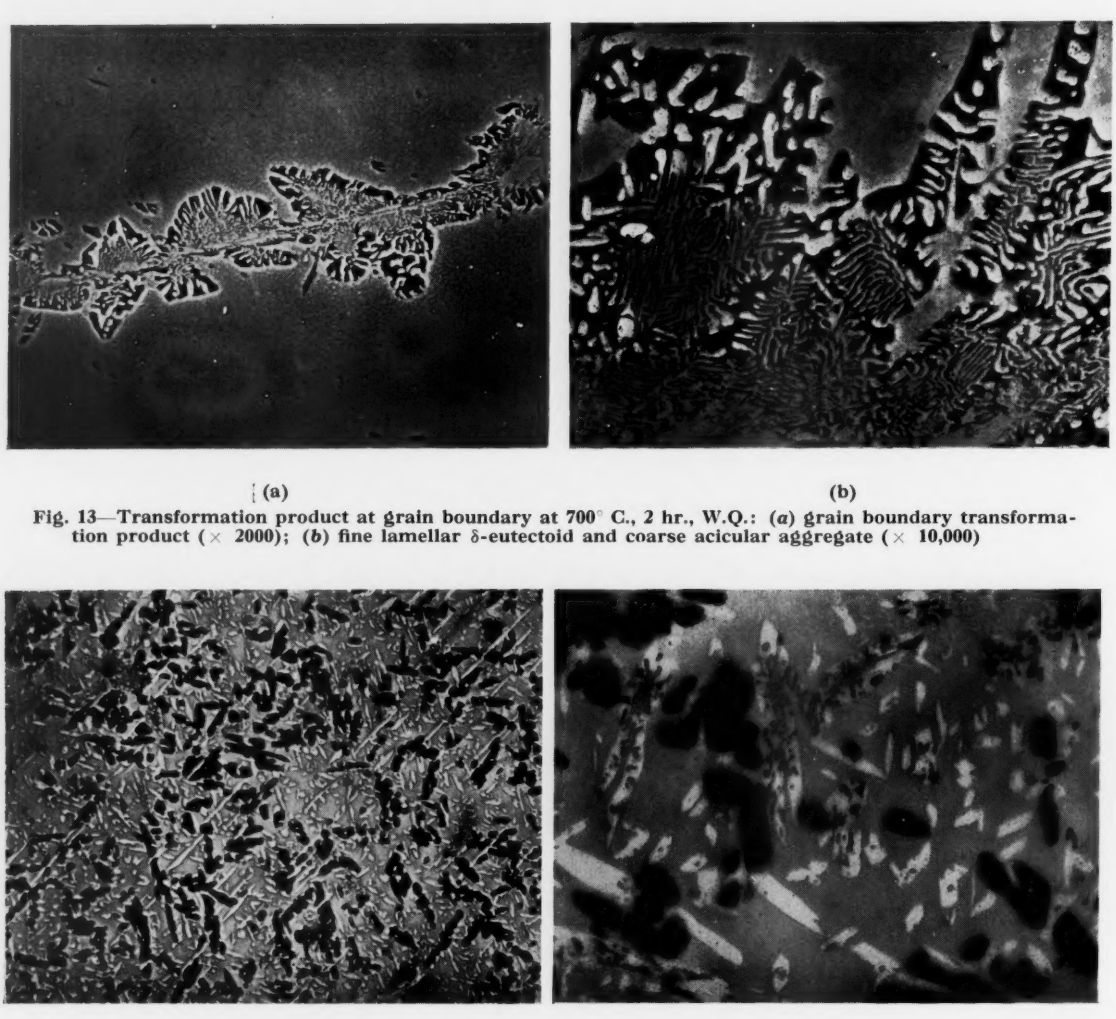
(a) (b)

Fig. 12—Acicular aggregate formed at 700° C., 2 hr., W.Q. (× 10,000): (*a*) two needles cut longitudinally; (*b*) a group of parallel needles cut transversely



(a) (b)

Fig. 13—Transformation product at grain boundary at 700° C., 2 hr., W.Q.: (*a*) grain boundary transformation product (× 2000); (*b*) fine lamellar δ-eutectoid and coarse acicular aggregate (× 10,000)



(a) (b)

Fig. 14—Formation of sigma at 700° C., 24 hr., W.Q.: (*a*) sigma forms between austenite rods in δ-ferrite (× 400); (*b*) sigma appears as large orange-coloured holes (× 2000)

Etchant: Vilella's reagent (Figs. 12, 13), Murakami's reagent (Fig. 14)

Figures 10*a* and *b* show that the acicular aggregate of austenite and carbide followed the same orientation as the austenite rods. This suggests that this acicular aggregate is nucleated by austenite, just as bainite is nucleated by ferrite. This aggregate in general is also larger than the austenite rod, a fact that may be explained by the mutual aid that the precipitation of austenite and carbide render to each other.

At 700° C.

At this temperature the acicular aggregate led the transformation of δ-ferrite and very often chromite inclusions were found in these aggregates (Fig. 11*a*). The small particles and needles are austenite in the early stage of formation. Figure 11*b* shows a group of parallel acicular aggregates around a chromite inclusion.

The electron micrographs of this acicular aggregate are shown in Fig. 12. In comparison with the δ-eutectoid formed at 800° C. (Fig. 9*b*), the carbide particles in the acicular aggregate formed at 700° C. are not only separated from each other but also bigger in size. This phenomenon is rather common in a mixed structure of pearlite and bainite formed at the same temperature. It seems that Fig. 12*a* shows two needles of this aggregate cut longitudinally and Fig. 12*b* a group of needles cut transversely.

A mixed structure of δ-eutectoid and the acicular aggregate also occurred in this steel at 700° C., but mainly along the grain boundaries (Fig. 13*a*). At a higher magnification (Fig. 13*b*), not only the carbide size and distribution but also the contour of austenite suggest that the fine aggregate of austenite and carbide is probably δ-eutectoid and the coarse one is probably the acicular aggregate. However, the possibility that this δ-eutectoid forms at a higher temperature on cooling to 700° C. cannot be excluded.

The FeCr sigma phase began to appear after 5 hr. at 700° C. and the structure after transformation for 24 hr. is shown in Fig. 14. It is not possible to differentiate the colour of sigma from $Cr_{23}C_6$ in these micrographs, but under a microscope the sigma phase appears as large and deep orange coloured holes and the $Cr_{23}C_6$ carbide as small black dots. Because of this the sigma phase shown in Fig. 14*b* is out of focus.

GENERAL DISCUSSION

In the present paper the formation of δ-eutectoid differs from those discussed before[1, 2] in that phases other than ferrite at the high temperature are absent, so that the eutectoid decomposition of δ-ferrite can be singled out for closer examination. In the ferrite–austenite duplex structure discussed[1] in Part I, there is always a long-range diffusion of carbon from the existing austenite to ferrite accompanying the eutectoid decomposition of δ-ferrite, which is governed by the short-range diffusion of the alloy element. Apart from this interference, a ferrite–austenite duplex structure always provides an enormous amount of phase boundary, which greatly facilitates the nucleation of a new phase. This not only moves the transformation curve towards shorter time but also affects the morphology of transformation, as shown before,[1] in that transformation generally starts from phase boundaries and grow into δ-ferrite grains.

The hypo-eutectoid nature of this δ-ferrite is exhibited by the formation of pro-eutectoid austenite and by the complete solution of carbide at a lower temperature (1150° C.) than that of austenite (1200° C.). By increasing the carbon content of the steel, this δ-ferrite may become eutectoid or even hyper-eutectoid in nature. In the former case, the complete solution of carbide and austenite occurs at the same temperature, and in the latter it requires a higher temperature for the complete solution of carbide. Therefore the nature of δ-ferrite depends in this respect upon whether the F single-phase region is separated from the $A + F + C$ 3-phase region by an $A + F$ or an $F + C$ 2-phase region. At the eutectoid composition there is direct contact between the F single-phase and the $A + F + C$ 3-phase regions.

The confirmation of the existence of an acicular aggregate of austenite and carbide, as predicted before,[1] makes the isothermal transformation of δ-ferrite exactly analogous to that of austenite, except that the former is governed by the diffusion of a slow-moving alloy element in ferrite and therefore occurs within a higher temperature range than the latter. From the observed orientation relationship between the acicular aggregates and austenite rods, it is tentatively suggested that the former is nucleated by austenite. This requires, of course, further confirmation by more accurate X-ray determination.

The presence of molybdenum is not a necessary condition for the formation of this acicular aggregate, since this transformation has also been observed in a steel with a similar analysis but containing only traces of molybdenum (0·061% C, 0·47% Si, 0·26% Mn, 27·8% Cr, 5·3% Ni, 0·12% Mo).

The decomposition of δ-ferrite into δ-eutectoid and a bainite-like acicular aggregate of austenite and carbide has also been found in 18–8–3 Cr–Ni–Mo steels, provided that they are heated to a sufficiently high temperature, so that a ferrite–austenite duplex structure can be obtained. This will be discussed in detail in Part IV of this series.[10]

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The Relative Merits of Low- and High-Sulphur Oil for Open-Hearth Steelmaking

By C. A. Edwards, D.Sc., F.R.S.

THE FACTORS THAT GOVERN THE DISTRIBUTION OF SULPHUR BETWEEN METAL AND SLAG

SYNOPSIS

The weights of sulphur pickup when using fuel oil with varying sulphur contents are given and from these the theoretical weights of tapping slag required have been calculated. The distribution of both phosphorus and sulphur between slag and metal is discussed mainly from the practical point of view. For sulphur it is concluded that the basicity of the slag cannot be the only factor that governs the (S)/[S] values but a satisfactory degree of correlation is found when these values are plotted against the products of slag basicity and residual manganese. 1148

THE MAIN REASON for making these notes was to collect evidence of the varying degrees of sulphur pickup when using fuels containing different percentages of sulphur, and to calculate the effects of this on the weight and character of the slag required for the production of steel of different sulphur contents. In this way it was hoped to help the steelmaker to estimate the relative values of low- and high-sulphur fuel oil.

Much of the sulphur in the slag plus metal at tapping may have been absorbed by the charge from the furnace flame, and this is increased proportionally by the sulphur content of the fuel used. Any increase in the sulphur load for this reason means that more slag is required for the production of steel of a specified sulphur content. This causes a decrease in the rate of production, the use of more limestone or lime, and a lower metallic yield owing to a greater loss of iron as oxides in the slag.

Apart from the weight of sulphur which may have to be removed other factors make it impossible to reduce the weight of slag below certain limits. One of the most obvious is the phosphorus content of the raw materials. This means that there is a relationship between the relative amounts of sulphur and phosphorus which have to be removed and the weight of slag that is required. If the sulphur load is exceptionally low, the slag weight under normal British conditions could be kept down to the minimum needed for the removal of the phosphorus, so that in attempting to estimate the injurious effects of increasing the sulphur load it is necessary to refer to the phosphorus side of the problem. If the maximum percentage of P_2O_5 the slag may carry at tapping were known this could then be used as a standard of reference when considering sulphur.

It is generally known that the upper limits for P_2O_5 in the slag vary with the SiO_2; with very low SiO_2, the P_2O_5 can be as high as 14·0% or more, but if the SiO_2 is in the region of 17–20·0%, the P_2O_5 must not be more than about 2·2% or 1·5%, respectively. These limiting ranges of composition relate to tapping samples; at earlier stages of the process the position is quite different, as Fig. 1 shows. This is a typical example of how the composition of the slag changes from almost immediately after the introduction of the hot metal up to about clear melt. In this instance, the charge consisted of 50% hot metal with 1·3% phosphorus. It will be seen from Fig. 1 that during the early stages of working the P_2O_5 is about 17% in spite of the fact that the CaO/SiO_2 ratio is quite low.

More than 90% of the phosphorus in the hot metal can be made to enter the slag in this way within 1–2 hr. after the metal has been charged, and while the carbon with metal is still quite high. There are two reasons for this: firstly, the temperature is comparatively low, and secondly, most of the oxygen for the oxidation of the phosphorus is supplied by direct contact with the ore.

To achieve an estimate of the maximum percentage of P_2O_5 a slag might be expected to carry under British conditions of working, a large number of results from different sources have been examined. As a first approximation it can be said that to make the [P] below 0·030% the $(CaO–2SiO_2)/P_2O_5$ ratio must be more than about 2·0. If some allowance is made for the influence of oxide of iron the results are in accordance with Fig. 2; the factor for the iron in the slag has been selected quite arbitrarily.

It was found that the results from one source do not fit in with Fig. 2. To demonstrate these differences more clearly, the results have been plotted on another

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Dr. Edwards was formerly Professor of Metallurgy at University College, Swansea.

Table I—SLAG AND METAL ANALYSES

Bath Analysis				Slag Analysis						$\frac{CaO - 1{\cdot}57P_2O_5}{SiO_2}$	$\frac{CaO - 2SiO_2}{P_2O_5}$
C	S	P	Mn	P_2O_5	SiO_2	CaO	MgO	MnO	Total Fe = FeO		
(*a*)											
0·086	0·032	0·012	0·092	6·4	4·0	42·8	4·5	6·3	30·8	8·2	5·44
0·083	0·028	0·011	0·100	2·4	7·2	45·6	5·8	7·1	30·1	5·8	13·0
0·075	0·026	0·014	0·086	2·0	6·9	40·5	8·8	5·7	34·0	5·4	13·3
0·075	0·028	0·014	0·084	1·8	6·6	44·0	6·7	5·5	32·7	6·2	17·0
0·070	0·026	0·011	0·080	1·9	6·3	41·6	5·4	4·7	36·4	6·12	15·2
0·073	0·030	0·014	0·096	6·8	4·7	46·4	4·9	4·6	29·8	7·6	7·87
0·075	0·030	0·010	0·098	2·3	7·0	46·8	5·4	6·3	30·4	6·2	14·5
0·055	0·030	0·010	0·046	3·7	3·7	40·7	6·9	4·7	38·7	9·4	9·0
0·065	0·030	0·012	0·090	2·8	7·3	42·7	8·3	7·0	29·8	5·3	10·0
0·070	0·026	0·010	0·100	4·9	5·7	44·0	5·3	6·0	32·2	6·4	6·65
0·060	0·028	0·010	0·130	1·5	8·5	44·1	4·0	7·1	31·4	4·9	10·0
(*b*)											
0·045	0·030	0·028	0·150	11·64	12·0	44·7	5·9	5·87	17·3	2·2	1·78
0·050	0·020	0·026	0·150	11·49	12·6	47·1	4·2	6·50	15·3	2·3	1·90
0·045	0·022	0·016	0·100	9·49	11·4	42·1	7·6	5·52	20·7	2·38	2·03
0·050	0·021	0·028	0·080	9·01	16·2	47·9	4·48	3·64	16·0	2·11	1·72
0·050	0·018	0·025	0·140	10·19	10·4	45·9	6·37	6·03	17·9	2·87	2·46
0·060	0·027	0·042	0·220	11·49	15·3	44·8	...	7·10	13·4	1·75	1·24
0·050	0·034	0·026	0·180	11·96	9·0	46·8	5·36	7·50	18·2	3·11	2·40
0·040	0·019	0·020	0·130	11·49	10·3	44·5	4·78	6·57	19·5	2·57	2·08
0·040	0·018	0·023	0·160	9·80	11·8	44·7	5·28	7·12	18·8	2·40	2·15
(*c*)											
0·070	0·033	0·027	0·100	3·63	10·0	44·4	10·24	3·35	24·8	3·87	6·8
0·070	0·040	0·029	0·150	4·97	9·4	47·2	8·18	4·10	22·5	4·18	5·91
0·080	0·036	0·030	0·150	5·34	8·9	44·6	9·28	4·10	24·3	4·07	5·00
0·070	0·038	0·032	0·120	9·2	7·9	44·3	8·05	4·84	22·5	3·78	3·09
0·060	0·045	0·031	0·100	7·54	8·2	42·6	10·58	4·08	23·4	4·00	3·47
0·060	0·036	0·032	0·140	3·03	12·3	42·2	15·03	4·28	19·8	3·04	5·80
0·050	0·025	0·028	0·110	3·77	6·9	42·6	10·39	6·70	26·4	5·32	7·63
0·060	0·028	0·030	0·100	6·07	6·6	43·5	9·27	4·84	26·3	5·15	4·99
0·060	0·042	0·032	0·090	5·42	7·1	42·0	11·75	2·25	28·2	4·72	5·14
0·070	0·048	0·034	0·160	10·67	8·3	44·0	8·03	5·37	20·3	3·29	2·56
(*d*)											
0·240	0·026	0·021	0·190	8·25	10·6	50·12	5·67	6·5	15·8	3·51	3·51
0·420	0·020	0·020	0·180	9·46	11·4	49·6	5·43	5·7	14·9	3·05	2·85
0·390	0·023	0·028	0·210	9·56	12·6	54·7	3·62	4·9	10·1	3·16	3·08
0·390	0·033	0·032	0·220	10·26	12·8	50·48	5·75	5·7	11·9	2·68	2·42
0·310	0·018	0·028	0·230	9·26	13·6	48·79	7·06	6·1	11·6	2·52	2·33
(*e*)											
0·100	0·034	0·036	0·220	9·3	8·0	41·4	8·69	10·03	18·5	3·35	2·73
0·120	0·028	0·040	0·260	6·02	9·0	44·7	7·60	10·03	18·5	3·86	4·45
0·140	0·034	0·036	0·240	9·04	8·8	40·4	7·32	12·02	18·1	2·98	2·52
(*f*)											
0·470	0·028	0·020	0·640	1·16	21·1	50·44	5·79	10·03	8·9	2·3	7·2
0·490	0·021	0·020	0·660	1·83	17·8	47·46	7·15	12·6	11·3	2·5	6·4
0·500	0·020	0·030	0·760	1·60	20·2	48·95	7·05	11·44	8·45	2·32	5·38
0·210	0·033	0·010	0·460	1·62	16·23	43·00	7·97	14·60	13·89	2·49	6·54

scale in Fig. 2, where the crosses represent the abnormal values just referred to. From an examination of the typical examples of slag and metal analyses given in Tables I(*a*)–(*f*) it will be evident that the relatively high phosphorus figures in Table I(*c*), which correspond with the crosses in Fig. 3, cannot be due to the carbon or manganese in the metal. It is true that when high residual manganese is produced by high MnO in the slag it is associated with higher phosphorus in the metal (*see* Table I(*c*)), but this does not appear to be so if it is due to comparatively low percentages of oxides of iron. This reference to manganese is not intended to imply that additions of ferro-manganese during refining do not cause phosphorus reversion, but simply that soon afterwards there is a return to the original balance unless the manganese added is sufficient to raise substantially the percentage MnO in the slag.

When these irregularities in the [P] during refining and tapping are considered the following observations may be of use.

(i) Apart from the direct effects of the available, or free, CaO above that required to satisfy the SiO_2 in the slag, the [P] must be influenced by the rate at which oxygen is supplied to the slag/metal interface

(ii) Pearson and Turkdogan[1] have shown theoretically that the activity of oxide of iron in basic slags is not proportional to the percentage present in the slag. This is indirectly confirmed by the results contained in Tables I(*a*)–(*f*)

(iii) For a given carbon in the bath, the oxide of iron increases as the slag becomes more basic

(iv) An increase in the viscosity of the slag must tend to reduce the rate at which a given percentage of oxide present can supply oxygen to the surface of the metal. There are good reasons for the opinion that both high MgO and MnO increase the viscosity of basic O.H. slags

(v) The surface area of contact between metal and slag in relation to the weight of metal must have a marked effect in this connection

(vi) For a given set of conditions regarding the

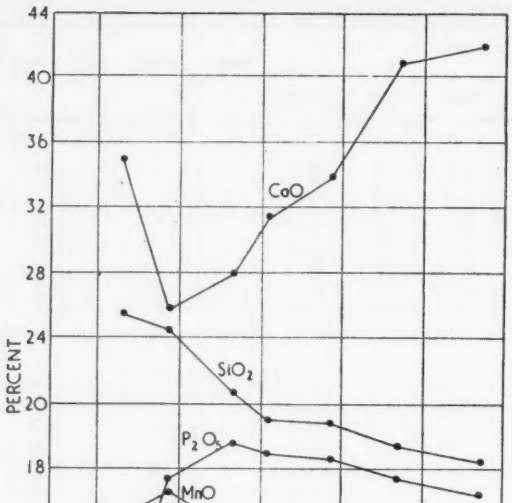

Fig. 1—Changes in composition of slag from soon after introduction of hot metal up to about clear melt

composition of the slag, etc., the author believes that the rate of oxygen supply must diminish as the thickness of the slag blanket increases, if only because the pressure at the slag/metal interface must be greater.

It seems probable that the less efficient removal of phosphorus in the case of the charges in Table I(*c*) must be due to one, or to a combination of the last three variables.

Perhaps the greatest difficulty is in estimating the viscosity of the slag, but it is significant that Dufty[2] says "From the operating angle, slags of 1·5 to 1·8 basicity give rapid heat transfer to the bath due to their low viscosity, and do not accelerate bank erosion." This must also mean a relatively higher rate of oxygen supply to the metal in spite of the fact that slags of this kind contain low percentages of oxide of iron.

There does not seem to be a simple method of correlating the [P] with that of the (P_2O_5) which will adequately cover all conditions of furnace working; but the anomalies appear to be confined to the representative examples which are included in Table I(*c*). It would be interesting and useful to know if this group can be brought into line with the others by the application of the laws of thermodynamics.

Effects of Fuel-Oils with Different Percentages of Sulphur on Weight of Tapping Slag Needed to Remove the Sulphur

It is necessary to give an outline of the bases on which the calculations have been made:

(i) It has been assumed that when working charges with 50% hot metal containing about 1·2% phosphorus, it is possible to finish refining with the slag containing 10·0% of P_2O_5, provided that there is little or no sulphur pickup. Also, if this percentage P_2O_5 is reduced by dilution, i.e. by using more limestone and/or lime, etc., the additional slag weight might be taken as a measure of the injurious effect of the extra sulphur pickup

(ii) A large number of carefully controlled charges were made for the determination of the degree of sulphur pickup when using liquid fuels containing different percentages of sulphur

(iii) In estimating the sulphur input from the solid materials, it was assumed that the scrap contained 0·060% sulphur, but the input from the hot metal, limestone, lime and ore was calculated from their known compositions

(iv) Complete analyses of the slag and bath samples at tapping were made, and the weight of tapping slag was calculated from the known weight of phosphorus in the charge and the P_2O_5 in the slag. In a number of instances these estimated weights of slag were checked on the basis of the CaO and/or manganese.

At first it was thought that the uncertainty about the sulphur content of the scrap might obstruct attempts to obtain reliable determinations of the amount of sulphur picked up from the furnace gases, but such a fear seems excessive.

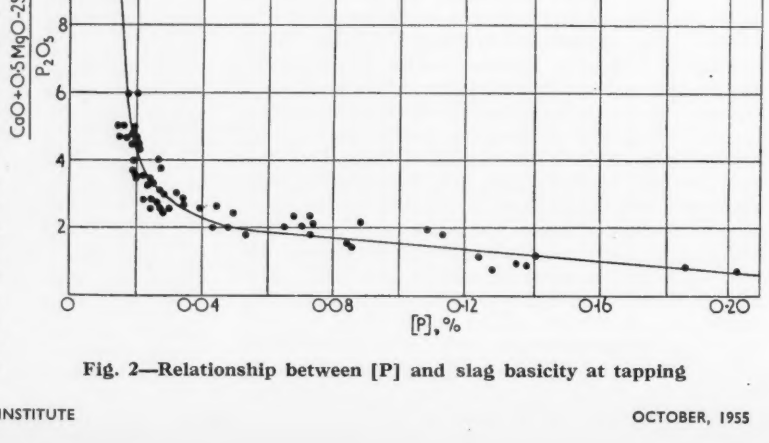

Fig. 2—Relationship between [P] and slag basicity at tapping

The evidence obtained indicates that a balance is reached between the sulphur which is absorbed by the melting scrap and the percentage of sulphur in the fuel oil used. This must mean that in dealing with a series of charges in which the scrap contains progressively higher percentages of sulphur, there should be a stage when using oil with a given sulphur content, at which there ought to be a net loss of sulphur from the charge, i.e. for sulphur to be lost from the melting scrap at a quicker rate than it is picked up from the furnace gases. To test this, special charges were made in which the whole of the scrap contained 0·25% sulphur, and two separate charges in which the sulphur in the hot metal was raised to almost 0·25%.

With the high-sulphur scrap charges it was found that the weight of sulphur in the slag plus metal at tapping was almost the same as that usually found when using normal scrap and any specified class of fuel-oil. This means there was a very substantial loss of sulphur from the charge when using rather low-sulphur oil under these conditions.

The position was quite different for the charges with the high-sulphur hot metal. In these charges the sulphur pickup was only a little less than was normally obtained for the class of oil used. A probable explanation of these differences is that there is a strong tendency for a state of equilibrium to be established between the sulphur which can be taken up by the melting scrap and the sulphur concentration in the furnace gases, so that when the sulphur in the scrap is very high there is a net loss of that element from the charge. This does not apply to high-sulphur hot metal, because almost immediately the hot metal enters the furnace it is covered with a layer of slag and isolated from the flame. There is then much less, if any, opportunity for the sulphur it contains to be removed from the charge.

It was considered that for the purpose of obtaining comparative figures for the sulphur pickup from different fuels, normal variations in the sulphur contents of the scrap would not have much influence on the results. For fixed furnace charges with 50% hot metal and 50% scrap, the average figures for sulphur pickup were as follows:

Sulphur in Fuel, %	Sulphur-Pickup, lb./100 tons of steel
1·0	25
1·3	40
1·7	60
2·3	90

It is interesting to note at this stage that the recent work by Trentini, Peters, and Husson[3] gives strong but indirect support to these results.

The above figures have been used to estimate the weights of slag required for the production of steel containing varying percentages of sulphur. No doubt the degree of sulphur pickup may vary in different plants especially with regard to the character of the flame, the rate of melting down, and the ratio of hot metal to scrap, etc. However, it is considered that the effects of high- compared with low-sulphur fuel upon the relative weights of slag required would be of the same order of magnitude as those found in the present calculations.

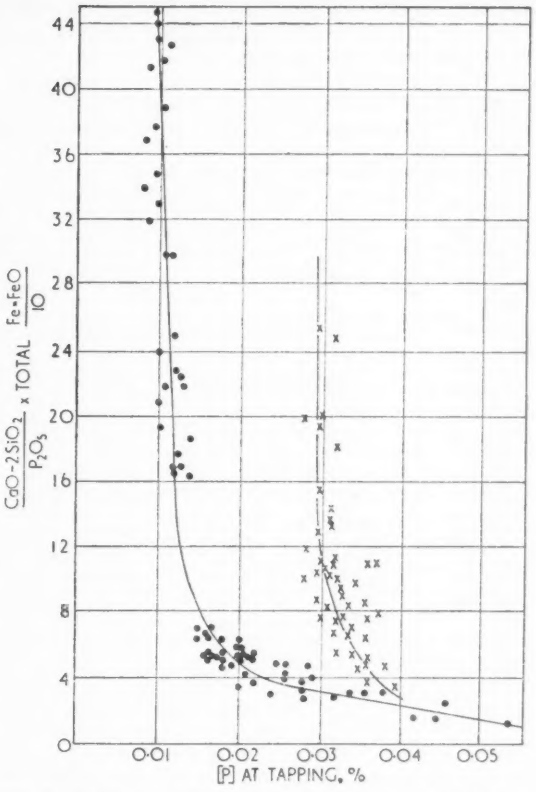

Fig. 3—With one set of working conditions indicated by crosses the [P] is much higher than is usually found

For the production of 100 tons of steel it has been assumed that the furnace charge would consist of 57·5 tons of hot metal with 0·050% sulphur, with the same weight of scrap with 0·060% sulphur. A charge of this kind with the necessary limestone and iron ore would contain 152·7 lb. of sulphur. Therefore, with the sulphur pickup values already referred to, the weight of sulphur in the slag plus metal at tapping when using the different fuels would be:

Sulphur in Fuel, %	Total Weight of Sulphur in Slag + Metal at Tapping, lb.
1·0	177·7
1·3	192·7
1·7	212·7
2·3	242·7

Obviously, the weight of slag required to carry the sulphur must be increased in accordance with the above figures, and this means that the weight of limestone charged must be correspondingly raised. To simplify the calculations the small amount of sulphur introduced in this additional limestone has been ignored because it would make no practical difference from a comparative point of view.

The following figures illustrate the relative influence of the sulphur that is picked up from the fuel, and that in the hot metal and scrap when each are expressed in terms of the percentage present in the slag plus metal at tapping :

Table II

REQUIRED SLAG WEIGHTS AND P_2O_5 CONTENTS

Sulphur in Steel	1·0% S Oil		1·3% S Oil		1·7% S Oil		2·3% S Oil	
	Tons of Slag	P_2O_5	Tons of Slag	P_2O_5	Tons of Slag	P_2O_5	Tons of Slag	P_2O_5
(*a*) For Fixed Furnace—No Flush Slag								
0·025	21·73	7·32	24·41	6·52	27·87	5·71	33·34	4·77
0·030	16·44	9·67	18·67	8·47	21·65	7·32	26·10	6·07
0·035	12·66	12·52	14·58	10·87	17·13	9·25	20·95	7·56
0·040	9·83	16·08	11·50	13·75	13·73	11·52	17·08	9·28
(*b*) For Tilting Furnace with 40% Phosphorus Removed in 6·0 tons of Slag per 100 tons of Steel (P in Iron, 1·2%)								
0·025	19·33	4·79	22·0	4·32	25·59	3·62	30·94	2·99
0·030	14·44	6·42	16·67	5·56	19·71	4·70	24·11	3·84
0·035	10·95	8·46	12·86	7·21	15·36	6·03	19·24	4·82
0·040	8·33	11·12	10·01	9·26	12·24	7·57	15·59	5·94
(c) For Fixed Furnace—No Flush Slag (P in Iron, 0·72%)								
0·025	21·73	4·33	24·41	3·89	27·87	3·41	33·34	2·85
0·030	16·44	5·78	18·67	5·09	21·65	4·89	26·10	3·64
0·035	12·66	7·51	14·58	6·52	17·13	5·55	20·95	4·54
0·040	9·83	9·67	11·50	8·27	13·73	6·91	17·08	5·56

Sulphur in Fuel, %	Sulphur in Charge from Hot Metal with 0·050, %	Sulphur in Charge from Scrap with 0·060, %	Sulphur in Charge from Fuel, %
1·0	36·2	43·5	14·0
1·3	33·4	40·2	20·7
1·7	30·3	36·4	28·2
2·3	26·5	31·9	37·1

If the hot metal contained only 0·025% the position would be as follows:

1·0	22·3	53·1	17·2
1·3	20·1	48·2	24·9
1·7	17·9	42·8	35·3
2·3	15·4	36·7	42·8

For the calculations which are referred to later it has been assumed that the P_2O_5 in the slag should be 10%, and the only reason for reducing it would be to increase the slag volume to meet the sulphur needs of the charge.

Selection of a Suitable Factor for the Distribution of Sulphur between Metal and Slag

After considering the many uncertainties connected with this it was decided to use the value of (S)/[S] = 10·0 for all cases. This may seem remarkable especially when it is remembered that the slag weight must be substantially increased when the sulphur load is raised. In practice this means that the tapping slag is more basic, and this is often thought to improve the sulphur partition. Whilst this may be true within certain restricted limits, there is no doubt that with very high slag basicities other influences neutralize the potential advantage of increasing the slag basicity.

Estimated Weight of Slag Required for Different Sulphur Loads

When operating fixed furnace charges, with no slag-flushing, all the P_2O_5 is in the final slag at tapping, but with a tilting furnace and good slag flushing it has been assumed that 40% of the phosphorus originally contained in the materials charged is carried off in the primary slag. This agrees with tests which have been made using about 50–60% hot metal.

The present calculations have been made on the basis that the hot metal contains 1·2% phosphorus and the scrap 0·060%. Therefore, after allowing for the phosphorus in the steel the tapping slags for the fixed furnace charges would contain 1·585 tons of P_2O_5 and those from the tilting furnaces 0·951 tons/100 tons of steel.

The estimated weights of slag required and the P_2O_5% they would contain, when using fuel of different sulphur contents and making steel with 0·025–0·040% sulphur, are given in Tables II(*a*) and (*b*), and comparable figures are given in Table II(*c*) for hot metal containing 0·72% phosphorus, for charges worked in a fixed furnace with no flushing.

It is unnecessary to refer to the figures in detail but a few general observations might be useful.

With Fixed Furnaces and Hot Metal with 1·2% Phosphorus

To produce steel with 0·025% sulphur, 21·7 tons of slag are needed when using fuel with only 1·0% sulphur but 33·3 tons are required when using fuel with 2·3% sulphur. For steel with 0·030% sulphur the corresponding figures would be 16·44 and 26·10 tons respectively.

If it is decided that the tapping slags must not contain more than 10·0% P_2O_5, then it will be seen from the figures in Table II*a* that when making steel with 0·035% and 0·040% sulphur the weight of tapping slag must not be less than about 17 tons, otherwise the P_2O_5 will be too high.

With Tilting Furnaces Working a Good Flush Slag Practice

With the removal of 40% of the phosphorus in the flush slag, the final weight of tapping slag can be substantially reduced and the P_2O_5 still kept well below 10·0%.

For the figures given in Table II(*b*) it has been taken that the weight of flush slag was 6 tons per 100 tons of steel. Since this slag usually contains 0·10% sulphur, this means that the weight of tapping slag, per 100 tons of steel, can be reduced by about 2·4 tons when making steel with 0·025% sulphur, and by 1·5 tons for steel with 0·040% sulphur.

From the figures in Tables II(*a*) and (*b*) it will be seen that if sulphur alone is considered, when using fuel with 1·0% compared with 2·3% sulphur, the weight of slag can be reduced as follows:

Sulphur Content of Bath at Tapping, %	Reduction in Weight of Tapping Slag per 100 tons of steel, with 1·0 instead of 2·3% S Fuel, tons
0·025	11·61
0·030	9·66
0·035	8·29
0·040	7·25

Of course the position is not so favourable if the slag must not contain more than 10·0% P_2O_5, and the hot metal contains 1·2% phosphorus when working without slag flushing, but it would hold if the hot metal contained only 0·72% phosphorus (*see* Table II(*c*)).

These differences in the weights of slag would have a marked effect on the yield of steel produced. This cannot be estimated accurately unless the conditions of working, etc., are known. It can, however, be stated that the percentage of iron in the slag increases with the basicity, and since the basicity normally rises with the slag volume the loss in yield is twofold: (i) with an increase in the weight of slag and (ii) with the higher percentage of iron in the slag.

When making low-carbon steel the iron content of the slag under average conditions may be taken as 16%, but it is often well above 20·0%.

Therefore, if the former figure is taken and the removal of sulphur alone is considered, the improvement in the yield when using 1·0 instead of 2·3% sulphur fuel would be:

Steel Made: Sulphur %	Increased Yield by Using 1·0 instead of 2·3% Sulphur Fuel, %
0·025	1·85
0·030	1·54
0·035	1·35
0·040	1·16

When the results in Tables II(*a*) and (*b*) are considered from the point of view of both sulphur and phosphorus, it will be evident that the advantages of using low-sulphur oil are greater when a good flush-slag practice is followed, or when using a lower-phosphorus hot metal with no flush slag, than when no flush slag is run off the charge with a high-phosphorus iron. Thus, for example, when no flush slag is run off the charge (as for Table II(*a*)) with 1·7% sulphur oil, and making steel with 0·035% sulphur, 17·0 tons of slag per 100 tons of steel are required, but on the other hand by removing 40% of the phosphorus in the flush slag, and firing with 1·0% sulphur oil, 11·0 tons of slag are sufficient, and this would contain only 8·46% P_2O_5.

Apart from the economic advantages which are associated with keeping the slag volume as low as possible, particularly concerning its effect on the rate of production and the yield, there are other indirect benefits which should not be overlooked. One of these is that so far as the weight of manganese in the materials charged and the carbon content of the bath are concerned, a substantial decrease in the weight of slag should lead to the residual manganese being maintained at a higher average level. The chief reasons for this are:

(i) As the slag volume increases, the percentage of MnO it contains diminishes by dilution
(ii) Under normal conditions of working an increase in the slag volume is usually brought about by using more limestone or lime, and this causes the basicity of the slag to be higher, which in turn means the slag will have a higher percentage of iron as oxides
(iii) Both these lower the manganese in the bath because this is proportional to the ratio MnO/FeO.

This has been fully discussed by McCance,[4] who deals with both the acid and basic processes of steelmaking. In each case there is a straight-line relationship between the above ratio and the manganese in the bath, but what may be described as the manganese recovery is much less for the acid process. There may be some doubt about the precise cause of this difference, but it can be accounted for on the assumption that in acid slags a good proportion of the MnO is chemically combined with SiO_2 and therefore cannot take part in the ratio MnO/FeO.

It is of interest to note that for the above purpose McCance separates the acid from the basic slags at a molecular ratio of $CaO/SiO_2=2·0$, that is, after deducting the CaO in combination with phosphorus as $3CaO.P_2O_5$.

Distribution of Sulphur between Slag and Metal

This is an interesting and important branch of the subject of steelmaking which has been studied and discussed in detail by many investigators. One of these, Taylor,[5] has given an excellent critical review of the work that has been published. The present author proposes to deal almost exclusively with the effects of oxide of iron in the slag on the sulphur partition.

There has been a tendency to think that the sulphur ratio increases with the basicity of the slag, but Herasymenko and Speight[6] found instances where the reverse effect took place. This was the case when the basicity exceeded a certain optimum value.

Grant and Chipman[7] concluded that the sulphur ratio is governed by the excess base in the slag, when this excess is expressed in terms of molar equivalents. Also, in their opinion the FeO present is always neutral, and therefore the only influence it can have on desulphurization is by acting as a diluent.

After examining hundreds of examples of slags and metal, taken at tapping, from a large number of sources, there appears to be no doubt that the influence of the oxides of iron must be taken into account before a reasonable degree of correlation between slag composition and sulphur distribution can be obtained.

Table III

EXAMPLES SHOWING HOW THE OXIDES OF IRON INCREASE AS SLAG BASICITY RISES

Bath C at Tap	CaO	MgO	SiO_2	P_2O_5	MnO	Total Iron Expressed as FeO	$\frac{CaO - 1{\cdot}57P_2O_5}{SiO_2}$	$\frac{CaO + MgO}{SiO_2 + P_2O_5}$
0·07	48·4	4·62	14·0	13·9	4·58	12·0	1·90	1·90
0·08	48·2	6·08	10·8	10·41	5·78	16·0	2·95	2·47
0·05	47·0	6·12	9·2	9·26	6·26	20·1	3·52	2·87
0·06	44·1	4·00	8·5	1·5	7·10	31·5	4·90	4·81
0·09	42·6	4·80	6·3	3·2	6·00	35·1	5·70	6·00
0·055	40·7	6·90	3·7	3·7	4·7	38·7	9·40	6·43
0·24	50·12	5·67	10·6	12·2	6·54	12·7	2·71	2·41

At this stage, however, it might be useful to emphasize that as well as providing oxygen for refining, the oxides of iron act as fluxes for some of the CaO and MgO that is present, and the amount required for that purpose increases with the basicity of the slag. Increasing the total weight of CaO in solution does not necessarily give a higher percentage CaO because of the extra oxide of iron that is required to get it into solution. This can be seen from Table III. At this stage it may also be noted from Table IV that increasing the percentage of MnO in the slag has the effect of lowering the percentage of CaO + MgO which can be held in solution.

Slag Basicity and Sulphur Distribution

When the (S)/[S] values are plotted against the corresponding slag basicities the degree of scatter is so pronounced that there can be no simple relationship between the two. Reference to the few examples taken from a large number and given in Table V will make this clear. As will be seen, some of the highest (S)/[S] ratios coincide with slags of low basicity, whilst many of the slags with unusually high basicity correspond with comparatively low sulphur ratios.

After a more careful and detailed examination of all the available data it was evident that the irregularities referred to above were in some way due to variations in the residual manganese, which in turn are caused by differences in the MnO/FeO ratios in the slag.

With this in mind the results were plotted as in Fig. 4, which shows a reasonably satisfactory degree of correlation between (basicity × Mn) and (S)/[S].

The influence of residual manganese may be indirect and caused by its effect on the oxygen content of the metal. The potential influence of oxygen in this respect was described many years ago by Manterfield[8] as follows:

> "The basic reaction involved is CaO + FeS ⇌ CaS + FeO . . . If the FeO was removed as formed the reaction from left to right could proceed to completion. Alternatively any addition to the FeO content would result in the reaction moving from right to left. Thus the oxygen content of the metal is, in the writer's opinion, a governing factor in the theory of desulphurisation, and . . . It is well known that desulphurisation of steel in the open hearth process requires a non-oxidising highly basic slag (perhaps it would be better to say a slag of low oxidising power). This necessitates a sufficiently high temperature. Fluorspar assists by increasing the fluidity of the slag at a given temperature, apart from any other role it may serve. The presence of deoxidants such as carbon, silicon, manganese, aluminium (and probably phosphorus) aids the attainment of equilibrium between metal and slag and promotes the condition wherein the slag carries its maximum proportion of sulphur."

These general statements agree with the results which have been found in the present paper, namely as the residual manganese increases, the sulphur ratio improves for any specified slag basicity. This is no doubt caused by the fact that for a given low carbon

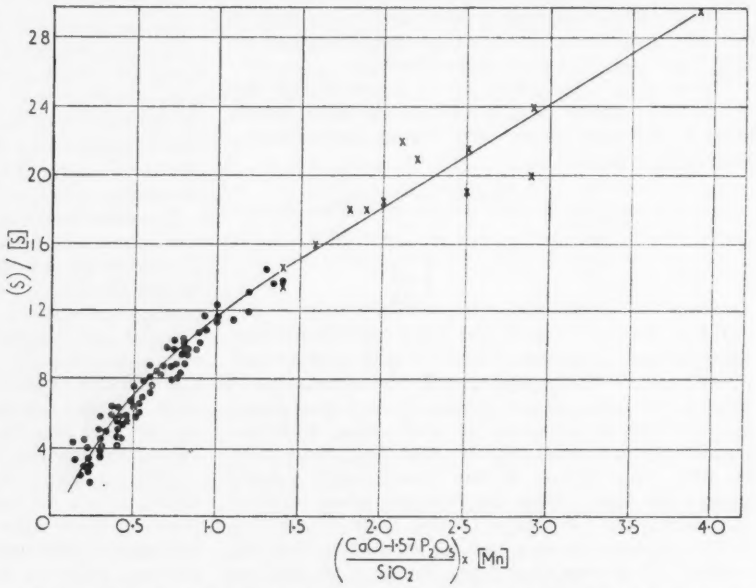

Fig. 4—By plotting slag basicity × [Mn] against (S)/[S], the degree of scatter is much less than when slag basicity alone is used

Table IV

TYPICAL INSTANCES OF PERCENTAGE CaO IN SLAGS CONTAINING HIGH MnO

Bath		Slag Analysis							$\frac{CaO - 1{\cdot}57P_2O_5}{SiO_2}$
C	Mn	CaO	MgO	SiO_2	P_2O_5	MnO	FeO	Al_2O_3	
0·22*	0·55	35·1	6·8	17·7	1·1	23·3	11·7	4·3	1·88
†	0·33	32·0		19·7	0·6	19·8	14·0	...	1·58
†	0·33	33·1		19·6	0·7	18·4	14·4	...	1·57
†	0·40	36·4		19·2	1·9	20·6	11·6	...	1·73
†	0·33	35·2		23·4	1·3	17·3	11·8	...	1·42
†	0·36	33·7		21·3	1·1	18·6	12·3	...	1·50

* Average of 50 heats from R. L. Knight, *J. Iron Steel Inst.*, 1943, No. I, p. 233P.
† From Dufty[3]

Table V

RESULTS TO ILLUSTRATE THAT THERE IS NO SIMPLE RELATIONSHIP BETWEEN SLAG BASICITY AND (S)/[S]

C	S	P	Mn	SiO_2	P_2O_5	CaO	MgO	MnO	Total Fe = FeO	S	$\frac{CaO - 1{\cdot}57P_2O_5}{SiO_2}$	$\frac{(S)}{[S]}$
0·04	0·033	0·020	0·080	10·50	10·05	44·2	6·12	4·27	20·41	0·110	2·7	3·35
0·07	0·040	0·024	0·11	14·0	13·9	48·4	4·62	4·58	12·09	0·126	1·9	3·15
0·04	0·019	0·023	0·09	11·1	7·33	46·5	5·72	4·44	21·32	0·145	3·15	7·63
0·30	0·019	0·045	0·27	11·4	13·59	49·56	4·91	5·70	11·44	0·137	2·48	7·21
0·05	0·017	0·020	0·15	9·2	9·26	47·0	6·12	6·26	19·8	0·137	3·53	8·06
0·24	0·026	0·021	0·09	10·6	8·25	50·12	5·67	6·54	15·86	0·151	3·51	6·04
0·06	0·018	0·022	0·11	9·7	9·56	43·47	6·81	6·06	21·06	0·103	3·97	5·72
0·06	0·019	0·015	0·14	9·1	9·18	48·50	5·50	5·60	18·85	0·142	3·74	7·47
0·06	0·031	0·020	0·26	14·0	2·16	38·96	13·52	11·76	16·76	0·22	2·53	7·10
0·11	0·034	0·030	0·39	16·28	2·88	44·70	7·01	11·36	15·93	0·31	2·40	9·10
0·55	0·018	0·030	0·33	9·85	4·41	46·44	4·29	10·92	22·25	0·26	4·01	14·44
0·31	0·025	0·030	0·40	13·21	3·26	44·27	9·02	12·66	14·98	0·30	2·96	11·00
0·46	0·026	0·020	0·46	13·75	2·63	47·68	9·12	10·38	13·75	0·35	3·17	13·46
0·30	0·037	0·020	0·44	15·67	2·70	43·84	9·53	13·35	12·58	0·38	2·52	10·25
0·077	0·032	0·012	0·056	4·60	4·20	45·0	7·80	4·50	30·68	0·23	8·80	7·2
0·087	0·028	0·013	0·088	5·00	6·10	44·6	6·20	6·28	29·90	0·26	7·0	9·3
0·072	0·026	0·011	0·074	3·80	4·30	46·0	5·40	4·20	33·40	0·24	10·3	9·2
0·055	0·030	0·010	0·046	3·70	3·70	40·7	6·90	4·70	38·74	0·14	9·4	4·7
0·060	0·028	0·010	0·130	8·5	1·5	44·1	4·00	7·10	31·46	0·21	4·9	7·5
0·082	0·032	0·010	0·126	4·9	4·9	42·5	6·60	7·30	30·00	0·22	4·9	6·9
0·065	0·030	0·012	0·090	7·3	2·8	42·7	8·30	7·00	29·30	0·21	5·3	7·1
0·12	0·048	0·038	0·21	8·7	10·03	43·6	8·26	7·93	18·07	0·39	2·98	8·12
0·10	0·034	0·036	0·22	8·0	9·30	41·4	8·69	10·03	18·46	0·28	3·35	8·24
0·12	0·028	0·040	0·26	9·0	6·02	44·7	7·60	10·03	18·45	0·35	3·86	12·5
0·15 *	0·044	0·032	0·19	7·1	10·49	46·8	7·89	6·70	16·77	0·45	4·28	10·23
0·10 *	0·043	0·030	0·12	6·0	7·54	43·2	8·94	6·33	24·57	0·39	5·23	9·07
0·15	0·032	0·032	0·23	9·9	5·79	50·5	6·01	6·51	14·17	0·37	4·18	11·57
0·11	0·040	0·034	0·26	8·3	8·20	44·9	6·56	8·74	19·50	0·47	3·86	11·75
0·10 †	0·038	0·035	0·23	7·5	10·00	46·8	7·96	4·00	19·89	0·42	4·10	11·05
0·09 †	0·035	0·032	0·18	7·8	6·62	46·8	6·62	3·34	23·53	0·35	4·66	10·00
0·12 †	0·029	0·033	0·14	8·1	6·26	49·0	7·97	5·40	20·00	0·30	4·83	10·34
0·13 †	0·031	0·034	0·13	8·9	8·74	48·6	8·76	2·42	18·60	0·29	4·37	9·35

* Both from same charge, one cast some time later than the other; these indicate how the (S)/[S] can decrease although there has been a substantial increase in the slag basicity
† All four charges, with liberal use of fluorspar

content the solubility of oxygen in the metal rapidly decreases as the residual manganese rises to about 0·35%.

The Effects of Variations in the Conditions of Working on Residual Manganese

In view of the important influence of residual manganese it might be useful to give a summary of how it can be caused to vary with different conditions of working:

(1) With a standard set of conditions of manganese input, and the carbon content at tapping, the residual manganese must diminish as the slag weight increases. This is caused by the dilution of the MnO in the slag, and also by the higher FeO the slag must contain as it becomes more basic.

(2) With a slag basicity of about 2·4, and a bath carbon of 0·22% the [Mn] will be about 0·46%, provided that the slag contains 14–15% MnO. The [Mn] will be more than 0·60% if the carbon is about 0·50 and the slag contains 10·0% MnO. Under these conditions the [FeO] is automatically kept low and the MnO/FeO will be approximately 1·0 and 1·2 respectively.

(3) Even with a high carbon content, say of the order of 0·55, the [Mn] will not be more than about 0·33 if the basicity of the slag is 4·0, and it contains as much as 11·0% MnO. This is because under these conditions the [FeO] must be approximately 22·0%. These figures are subject to small variations if there is much change in the relative amounts of SiO_2 and P_2O_5.

(4) With a bath carbon at tapping of, e.g., 0·10 and 0·12 and a slag basicity of 4·0, the residual manganese will be between 0·23 and 0·26 if the slag contains about 10·0% MnO.

(5) With a bath carbon of from 0·06 to 0·08 the maximum possible manganese appears to be about 0·23, if the slag basicity is about 4·0, but it may be 0·33 if the basicity is only 2·5 and the MnO is 10·0%.

(6) From the limited number of tests which have been made with the liberal use of fluorspar, there are some indications that the manganese in the bath is higher than it would be under corresponding conditions but with no spar. Many more carefully planned tests will be required before this can be regarded as a general rule.

CONCLUSIONS

From an extensive series of test charges when using 50% hot metal and 50% scrap it was found that the sulphur pickup from the furnace gases was:

Sulphur in Liquid Fuel, %	Sulphur Pickup per 100 tons of Steel, lb.
1·0	25
1·3	40
1·7	60
2·3	90

These figures have been used in estimating the weight of slag for the production of steel with varying sulphur contents.

Two sets of results are given on the assumption that the hot metal contained 1·2% phosphorus and (*a*) the operations were carried out in a fixed furnace with no flush slagging and (*b*) in a tilting furnace from which the primary slag contained 40% of the phosphorus from the raw materials used. A comparable set of figures are also given for fixed-furnace charges for which the hot metal contained only 0·72% phosphorus.

In considering the results it is suggested that a useful but arbitrary standard of reference for the maximum permissible P_2O_5 in the tapping slag would be 10·0%. This figure is selected because it represents a reasonably high degree of efficiency for phosphorus removal, but the estimated percentages of P_2O_5 are shown for the different weights of slag.

The results indicate that for the production of 100 tons of steel with 0·025% sulphur, about 11·6 extra tons of slag are required if the fuel contains 2·3% sulphur than if the fuel contained only 1·0% sulphur. The relative position is much the same if 40% of the phosphorus is removed in the primary slag, because the weight of sulphur which must be carried in the tapping slag is not much less; but of course under these conditions the P_2O_5 in these slags would be correspondingly lower.

The theoretical weights of slag needed for the removal of sulphur for the production of steel with varying sulphur contents and when using the different grades of fuel are given. From these it will be seen that the beneficial effects of using low-sulphur fuel become less pronounced as the steel specifications are less rigid, and this is even more marked if the phosphorus load at tapping is high. In other words, when making steel with 0·035–0·040% sulphur, from hot metal with 1·2% phosphorus, and no slag flushing, the full advantages of using low-sulphur fuel are not realized because the minimum weight of slag needed for the removal of sulphur is not sufficient to dilute the phosphorus in the slag below 10·0% P_2O_5, which was suggested as the maximum permissible figure. These limitations do not prevail when 40% of the phosphorus is removed in the flush slag on one hand, or if the hot metal contains only 0·72% instead of 1·2% phosphorus without slag flushing on the other.

In general terms it can be said that whatever the sulphur specification of the steel may be, substantially less tapping slag is required when low- compared with high-sulphur oil can be used, provided that the phosphorus load of the charge can be kept below certain limits.

The question of the distribution of sulphur between metal and slag is discussed at some length, and it is shown that the basicity of the slag cannot be regarded as the only governing factor. A satisfactory degree of correlation is found when the products of basicity and residual manganese are plotted against the corresponding (S)/[S] values. Because of this relationship an attempt is made to give the outlines of the way in which the residual manganese varies under different practical conditions of basic O.H. steelmaking.

Acknowledgments

The large number of test charges dealing with different aspects of the sulphur problem on which the present contribution is largely based were made at the suggestion of Mr. T. Jolly, Joint Managing Director of Guest Keen Iron and Steel Co., Ltd.

Throughout the work, the author has had the benefit of the advice and many helpful suggestions from Mr. N. Gray, Chief Metallurgist, and Mr. S. Williams, Melting Shop Manager, and he wishes to express his appreciation of the valuable assistance they have given. He would also like to say how much he is indebted to Mr. Ivor Harris for his careful supervision of the special charges that have been made.

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A Microscopical Examination of Samples of Iron containing Titanium-bearing Inclusions

By F. B. Pickering, A.Met., A.I.M.

SYNOPSIS

A detailed microscopical examination has been carried out on samples of iron containing titanium-bearing inclusions, along the lines adopted for the previous investigations on manganous, aluminous, and siliceous inclusions. The object of the examination was to establish means of identification by the determination of optical and chemical characteristics of the inclusions. The unreactive nature of many of the inclusions, however, has resulted in very limited use being made of the chemical characteristics. 1157

IN ORDER TO COMPLETE the work on the iron–oxygen alloys deoxidized by various deoxidants, it was decided by the former Solid Steel Study Group to supplement the examination carried out by Evans and Sloman[1] by a detailed microscopical examination. This work was to follow on the lines previously adopted by Lismer and Pickering,[2–4] and it was hoped that the data would provide useful identification methods for some types of titanium-bearing inclusions.

Material Examined

Samples were selected from ingots *TB*, *TD*, *TF*, *TG*, *TL*, *TM*, *TP*, and *TQ* of the series described by Evans and Sloman, and were carefully examined to determine any chemical or optical properties which might help identification of the inclusions.

The crystalline constituents of each of the ingots were determined by X-ray analysis of alcoholic iodine residues, the results being shown in Table I, which is abstracted from that published by Evans and Sloman.

Polishing Technique

The polishing technique and methods of microscopical examination were similar to those used by Lismer and Pickering.[2–4]

Method of Examination

The following scheme of examination was used:

(*a*) Normal vertical illumination using a light etch in alcoholic 2% nitric acid as desired
(*b*) Polarized vertical illumination
(*c*) Etching with alcoholic 10% nitric acid
(*d*) Etching with aqueous 10% chromic acid
(*e*) Etching with alcoholic 5% hydrochloric acid
(*f*) Etching with aqueous 20% hydrofluoric acid.

Whiteley's test for sulphides was not used because of the negligible amount of sulphide present.

Paper SM/C/179/54 of the Physical Chemistry Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 29th April, 1955. The views expressed are the author's and are not necessarily endorsed by the Committee as a body.

Mr. Pickering is with the Research and Development Department of The United Steel Companies, Ltd.

Table I

X-RAY ANALYSES OF RESIDUES FROM INGOTS DEOXIDIZED BY TITANIUM
(Abstracted from the results of Evans and Sloman)

Ingot	TiO	αTi_2O_3	Ti_3O_5	TiO_2 (Rutile)	$FeO.TiO_2$ (Ilmenite)	Titanian Magnetite Spinel	Fe_3O_4 (Magnetite)	'X' (unidentified)
TB	...	>90%	...	...	...	...	...	Present
TD	...	>90%	...	...	...	...	...	Present
TF	...	60%	40%	...	...	...	...	...
TG	20%	80%	...	...	...	...	...	...
TL	...	...	...	80%	...	...	...	...
TM	...	...	...	...	60%	40%	...	...
TP	...	...	...	...	...	>90%	...	...
TQ	...	...	...	...	...	60%	20%	...

The figures denote estimated percentages of the total

EXPERIMENTAL RESULTS

Examination under Normal Vertical Illumination

Ingot TB

The inclusions were mainly αTi_2O_3, occurring as both isolated particles and as irregular clusters. Their colour varied from brown to purple and they occurred in two main forms:

(i) Spherical particles often containing small iron particles (Fig. 1)
(ii) Irregular clusters of particles (Fig. 2). Some of these inclusions contained sharply differentiated bands, similar to twinning, across them.

Very occasionally a small cubic yellow-coloured phase was observed (Fig. 3), appearing very similar to titanium nitride. Sometimes this yellow phase occurred together with αTi_2O_3 (Fig. 4). A similar type of inclusion to those shown in Fig. 4 has been observed in a commercial stainless steel containing titanium.

Ingot TD

The inclusions were mainly αTi_2O_3 and appeared very similar to those in ingot *TB*. Again the cubic yellow phase was seen in conjunction with αTi_2O_3 (Fig. 5).

Ingot TF

Mainly αTi_2O_3 was present, but many particles showed banding or twinning (Fig. 6), as described earlier. No phase corresponding to the Ti_3O_5 which was identified by X-ray analysis could be observed microscopically. A little of the yellow cubic phase was observed in conjunction with the αTi_2O_3.

Ingot TG

The inclusions were mainly typical αTi_2O_3 particles, often containing some of the cubic yellow phase previously described. This yellow phase often occurred as a thin layer around the periphery of the αTi_2O_3. Occasionally the inclusions were crossed by the bands previously described (Fig. 7) and sometimes small needles appeared within the αTi_2O_3 (Fig. 8).

The presence of TiO, which was inferred from the X-ray results of Evans and Sloman, may mean that the yellow phase in the first four samples was TiO, although it has every appearance of titanium nitride.

Ingot TL

The inclusions were mainly small round dark-grey globules, sometimes showing traces of an inner structure (Fig. 9). In the larger inclusions, their duplex and polycrystalline nature was very apparent (Fig. 10). X-ray analysis had identified these inclusions as being mainly rutile (TiO_2).

Ingot TM

Mainly spherical grey inclusions, some being single-phase, whilst others were duplex. In the duplex particles the colours ranged from grey to fawn (Fig. 11).

X-ray analysis had identified two phases:

(i) A titanian magnetite spinel
(ii) Ilmenite

in this ingot, but it was not possible to identify these constituents under the microscope.

Ingot TP

Round, medium-grey inclusions showing an inner structure which may have been due either to polycrystallinity or to the presence of a second phase (Fig. 12). These inclusions had been identified by X-ray analysis as being mainly titanian magnetite spinel.

Ingot TQ

The inclusions were rather irregular in shape, grey in colour, and often contained particles of ferrite and a lighter-grey phase. Many of them were single-phase, whilst the duplex ones showed a dark-grey phase in a lighter-grey matrix (Fig. 13). From the amount of each phase present, it was presumed that the lighter-grey matrix was magnetite and the darker grey particles the titanian magnetite spinel.

Examination under Polarized Light

In ingots *TB*, *TD*, *TF*, and *TG*, the αTi_2O_3 showed a change in colour as either the specimen was rotated or the analyser was rotated about the 'crossed' position (cf. Figs. 14 and 15). The change in colour was from a chocolate brown to a neutral blue-grey. The cubic yellow phase did not show any anisotropic effects.

In ingot *TF*, the twinning effect was very clearly shown up under polarized light, the colours of the bands interchanging as the microscope stage was rotated. Occasionally inclusions showing a very fine series of 'twins' were observed (Fig. 16). In ingot *TG* a polycrystalline form of αTi_2O_3 was found, showing much evidence of banding (Fig. 17). Again, the yellow cubic inclusions did not polarize.

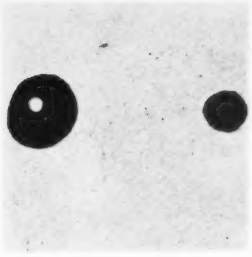

Fig. 1—Ingot *TB*: Spherical αTi_2O_3 × 2000

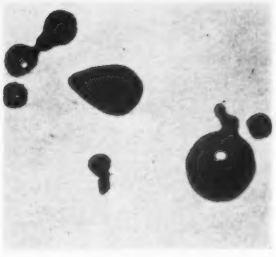

Fig. 2—Ingot *TB*: Group of αTi_2O_3 × 1500

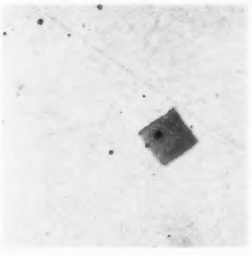

Fig. 3—Ingot *TB*: Yellow cubic phase × 2000

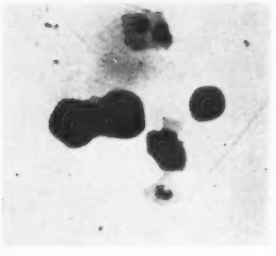

Fig. 4—Ingot *TB*: αTi_2O_3 and yellow cubic phase × 2000

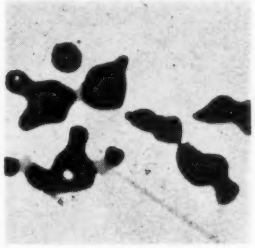

Fig. 5—Ingot *TD*: αTi_2O_3 and yellow cubic phase × 1500

Fig. 6—Ingot *TF*: αTi_2O_3 crossed by 'twins' × 1500

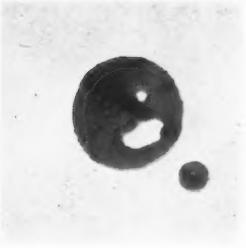

Fig. 7—Ingot *TG*: αTi_2O_3 crossed by 'twin' band × 1500

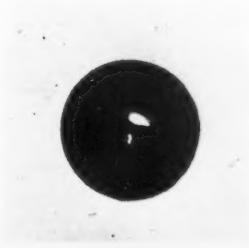

Fig. 8—Ingot *TG*: Spherical αTi_2O_3 with darker needles × 1500

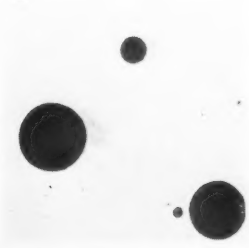

Fig. 9—Ingot *TL*: Spherical inclusions of rutile (TiO_2) × 1500

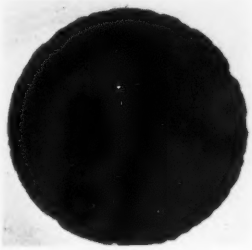

Fig. 10—Ingot *TL*: Mainly rutile (TiO_2) but polycrystalline and duplex × 1500

Fig. 11—Ingot *TM*: Duplex inclusion (ilmenite and titanian magnetite spinel) × 1500

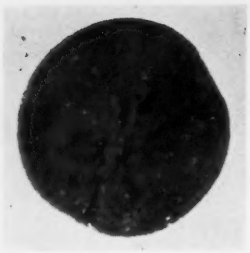

Fig. 12—Ingot *TP*: Typical inclusion of mainly titanian magnetite spinel showing an inner structure × 1500

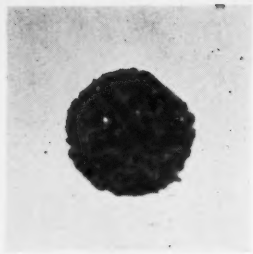

Fig. 13—Ingot *TQ*: Titanian spinel and magnetite × 1500

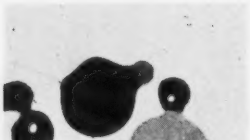

Fig. 14—Ingot *TB*: Ti_2O_3 (polarized light; crossed polarizer and analyser) × 1000

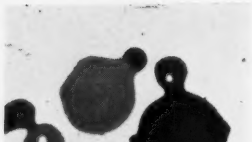

Fig. 15—Ingot *TB*: As Fig. 14, specimen rotated 90° × 1000

Fig. 16—Ingot *TF*: Extensive series of 'twin' bands in αTi_2O_3 (polarized light) × 1000

Fig. 17—Ingot *TG*: Polycrystalline αTi_2O_3 with 'twin' bands × 1000

Fig. 18—Ingot *TL*: Polycrystalline rutile (polarized light) × 1000

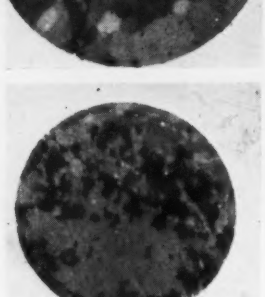

Fig. 19—Ingot *TM*: Polycrystallinity revealed by polarized light × 1000

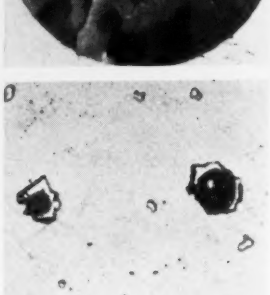

Fig. 20—Ingot *TM*: As Fig. 19, specimen rotated 90° × 1000

Fig. 21—Ingot *TP*: Duplex nature revealed by polarized light × 1000

Fig. 22—Ingot *TG*: Rim of yellow phase clearly revealed by etching with 10% nitric acid × 1000

The rutile TiO_2 in ingot *TL* was clearly shown by polarized light to be polycrystalline, neighbouring crystals becoming alternately light and dark as either the specimen or the analyser was rotated (Fig. 18). Under polarized light the rutile appeared deep-red in colour.

A similar example of polycrystallinity was seen in the inclusions in ingot *TM* (Figs. 19 and 20), but no effects were observed from the duplex particles.

In ingot *TP* the duplex nature of some of the inclusions was more readily shown up under polarized light (Fig. 21), but the single-phase particles did not polarize.

None of the inclusions in ingot *TQ* reacted to polarized light.

Alcoholic 10% Nitric Acid Solution

This reagent did not attack any of the inclusions, its only effect being to cause them to stand in heightened relief due to attack on the matrix metal. Because of this effect, the reagent was most effective in revealing the cubic yellow particles and the rim of the yellow phase around αTi_2O_3 in ingot *TF*. This rim of the yellow phase was often seen to have an angular outline (Fig. 22).

Aqueous 10% Chromic Acid

This reagent did not attack the inclusions present in any of the ingots, even in times up to 10 min.

Alcoholic 5% Hydrochloric Acid

No attack was obtained with this reagent on the inclusions in ingots *TB*, *TD*, *TF*, *TG*, and *TL*, but a roughening effect was observed on the surfaces of the ilmenite–titanian-magnetite-spinel inclusions in ingot *TM*. The predominantly titanian magnetite spinel inclusions in ingot *TD* were unattacked, but in the presence of magnetite in ingot *TQ* all the inclusions were dissolved out.

It appears therefore that whilst this reagent does not attack the titanian magnetite spinel, if either ilmenite or magnetite are also present dissolution does occur. This may be due to the other phase being attacked, thereby allowing the titanian magnetite spinel to fall out.

Aqueous 20% Hydrofluoric Acid

The inclusions in ingots *TB*, *TD*, *TF*, and *TG* were not attacked. The rutile in ingot *TL* was only slightly attacked, as was the titanian magnetite spinel, but the duplex inclusions in ingots *TM* and *TQ* were completely dissolved out.

DISCUSSION OF RESULTS

A considerable range of inclusions formed by the deoxidation of iron by titanium has been observed, but in many cases it has not been possible to distinguish, either optically or by means of etching reagents, the various phases identified by X-ray residue analysis. For this reason, it has not been found possible to draw up a table of identification as has been done in the previous work of this type.

Ingots *TB*, *TD*, *TF*, and *TG*

It has been possible to distinguish αTi_2O_3 by means of its very characteristic colouring, form, and anisotropy. Unfortunately, none of the etching reagents used has preferentially attacked this oxide and so chemical identification has not been possible.

The inclusions in ingot *TF*, reported by residue analysis to contain some Ti_3O_5, were very similar to αTi_2O_3 except that a large proportion of them showed the characteristic 'banding' or 'twinning' effect. However, this effect was not confined solely to the inclusions in ingot *TF* so that it is not probable that these bands are Ti_3O_5; therefore, Ti_3O_5 has not been distinguished microscopically. The yellow cubic phase, often associated with αTi_2O_3, has every appearance of titanium nitride, although it could be the TiO phase reported in ingot *TG*, as both TiO and TiN have very similar crystal structures and may be similar in appearance under the microscope.

Ingots *TL*, *TM*, *TP*, and *TQ*

Many of the inclusions in these four ingots were either polycrystalline, as revealed by polarized light, or duplex. All were grey in colour and it was impossible to identify each phase with certainty.

The single-phase particles in ingot *TL* were presumably rutile, and yet the predominantly titanian magnetite spinel inclusions in ingot *TP* appeared duplex.

The effect of hydrochloric and hydrofluoric acids was interesting, as both attacked inclusions containing iron, especially if the inclusions were duplex. Rutile in ingot *TL* was slightly attacked by hydrofluoric acid but not by hydrochloric acid.

Owing to the highly refractory nature of titanium oxides, it is doubtful whether attack can be obtained by wet reagents which do not also destroy the polished surface. It seems to be in line with analytical experience, however, that TiO_2 can be dissolved or attacked by hydrofluoric acid. The presence of iron oxides together with the titanium oxides might also be expected to result in some attack by hydrofluoric and hydrochloric acids.

In conclusion it would appear that the use of normal types of etching reagent holds very little prospect of positively differentiating between ilmenite, titanian magnetite spinel, and magnetite.

Acknowledgments

The author wishes to thank Mr. F. H. Saniter, Director of Research, The United Steel Companies, Ltd., for permission to publish this paper; he also acknowledges the assistance received from members of the Solid Steel Study Group of the former Gases and Non-Metallics Sub-Committee.

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Underground Mining of the Frodingham Ironstone Bed

AT THE DRAGONBY MINE, SCUNTHORPE

By C. Smith, M.I.Min.E.

SYNOPSIS

The paper concerns the working in North Lincolnshire of an extensive deposit of low-grade ironstone which, because of its valuable self-fluxing properties, can be used in considerable quantities for making pig iron.

Requirements in the past have been met by extracting the ironstone in increasing quantities from the ground by various methods of opencast mining. The author explains why this method cannot be continued indefinitely and describes the opening seven years ago and the subsequent working of a developing underground mine, which is expected to produce at least 1,000,000 tons per annum for many years from a large area which otherwise might not be worked. 1207

Introduction

GEOGRAPHICALLY the Frodingham ironstone bed is located in north-west Lincolnshire, between the Rivers Trent in the west and Ancholme in the east. The concealed field has been proved to dip gently at about 1 in 65 from west to east as it extends underground beneath deepening cover for a considerable distance from Ashby Ville in the south as far north as a line running east–west, just south of Winterton, across to Scabcroft on the Ancholme, but nothing is known of its extent, quality, or economic possibilities east of this point. Further south it has been incompletely proved almost as far as Ermine Street, but it is quite probable that it will continue beyond this point; only extensive deep borings can prove or disprove this in the distant future. It is lenticular in shape with the thin edge, due to erosion, towards the west, and is thickest towards the east where it is known to exist between 30 and 32 ft. Compared with other standards it is a low-grade ironstone, but because of its good fluxing properties it can be used in considerable quantities for making pig iron.

It has been worked economically for almost a century by various methods of opencast mining, first along its southern edge, but mainly along its western edge, where today many of the working faces, as they advance eastwards with the general dip of the Bed and against sharply rising surface contours, are meeting such thicknesses of overburden as will eventually make them either uneconomical or impracticable, or both. No one can at present say definitely where this limit will be, but even if the largest, most powerful, and (incidentally) very costly machinery contemplated in the future is used, by far the larger area of the deposit will be beyond its scope.

To safeguard against all emergencies, and to ensure continuity of the large tonnages required for future generations, the extensive reserves still held concealed beneath the thicker cover must be obtained from underground mines.

Figure 1 is a plan of the Scunthorpe district and shows the Frodingham ironstone bed as it is known to exist today, and Fig. 2 is a section through the field from west to east, showing clearly the increasing thickness of overburden.

ORE PRODUCTION POLICY

Realizing this position some years ago, the Board of The United Steel Companies Ltd., under the chairmanship of Sir Walter Benton Jones, Bt., decided to obtain valuable information about the bed by financing and carrying out a comprehensive prospecting and core-boring programme. From the data obtained, together with what was already known from geological and other sources, an accurate picture covering a large area of the field was built up, which formed the basis of a decision to start an underground mine.

It was appreciated that the ironstone produced during the development of such a mine, involving new techniques and ultimately capable of a large potential output, must for a time be more costly than that produced by opencast methods but, taking the long-term view, if it were begun early enough, the ore produced would not only supplement but would also conserve that from opencast working, thus prolonging the overall economical transitional period.

AREA AND SITE

The exploration and core-boring programme had proved there to be an extensive area in the Roxby district free from any major geological disturbances—apart from one or two faults which ran in an east–west direction along its southern edge—which contained several million tons of ironstone of commercial value, but which, because of its depth, could not be worked

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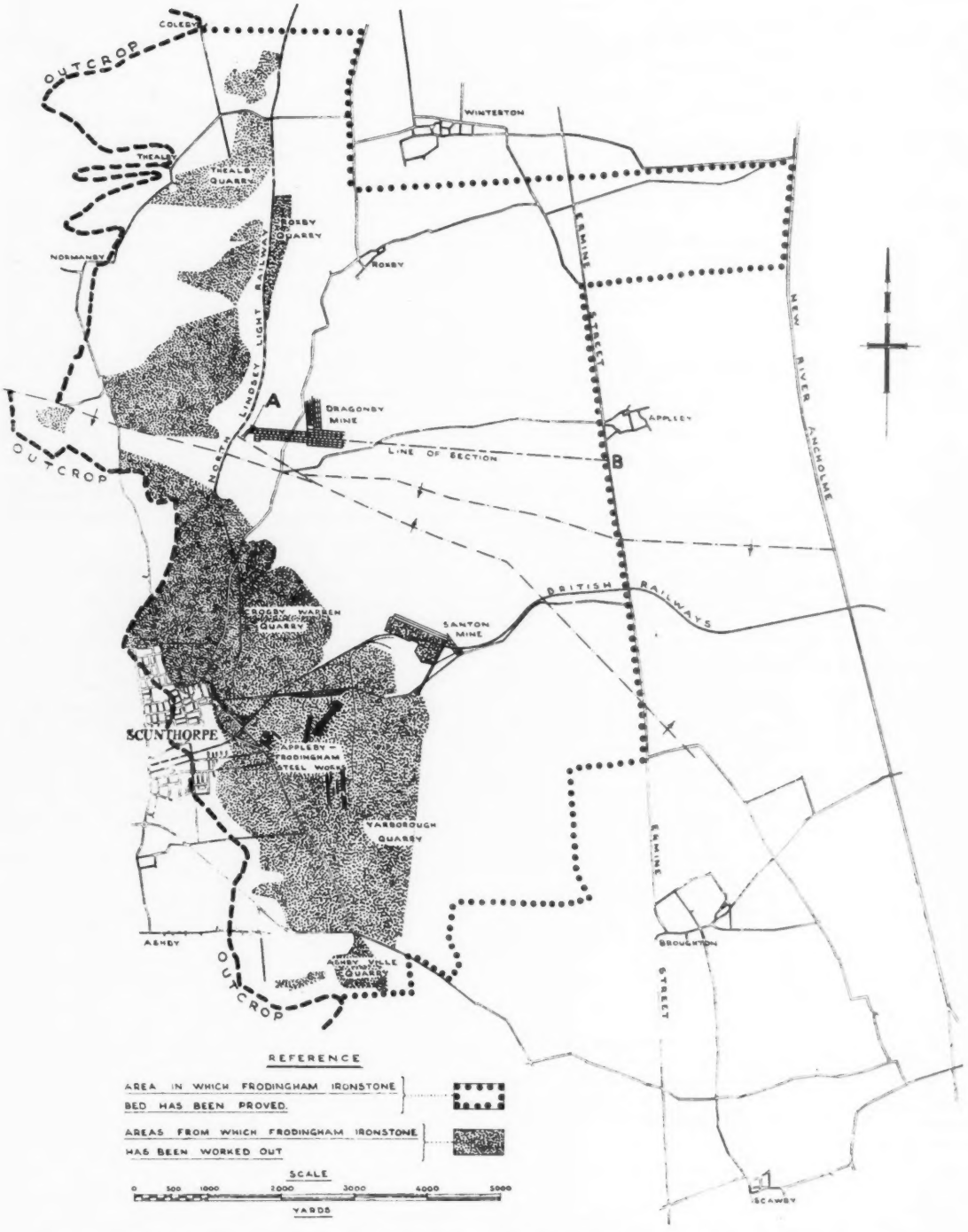


Fig. 1—Plan of Scunthorpe district, showing extent of Frodingham ironstone bed as at present proved

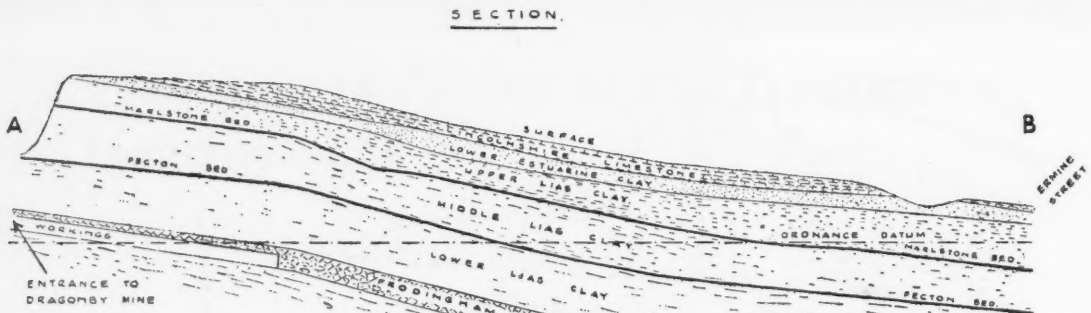


Fig. 2—Section through Frodingham field from west to east

by opencast mining. Provided that the faults were avoided, there seemed to be no reason why it could not be developed from its western side so as to justify the capital outlay of an underground mine.

The site selected was just north of the village of Dragonby, where an escarpment running north and south and parallel with the North Lindsey Light Railway would permit access to be made and adit levels to be driven in an easterly direction following the general dip of the bed under rapidly thickening cover.

The strata at this point consisted, in descending order, of a layer of soil, 10 ft. or so of blown sand, 50 ft. of blue clay down to 30 ft. of ironstone with a clay floor.

PLANNING AND UNDERGROUND LAYOUT

The mine was planned to produce, by stages, 1,000,000 tons per annum, and in order to keep manpower at a minimum was to be mechanized to the fullest possible extent. This meant that the conventional methods of underground mining (picks, shovels, etc.) had to be replaced by modern methods. It was decided that this could best be done by using

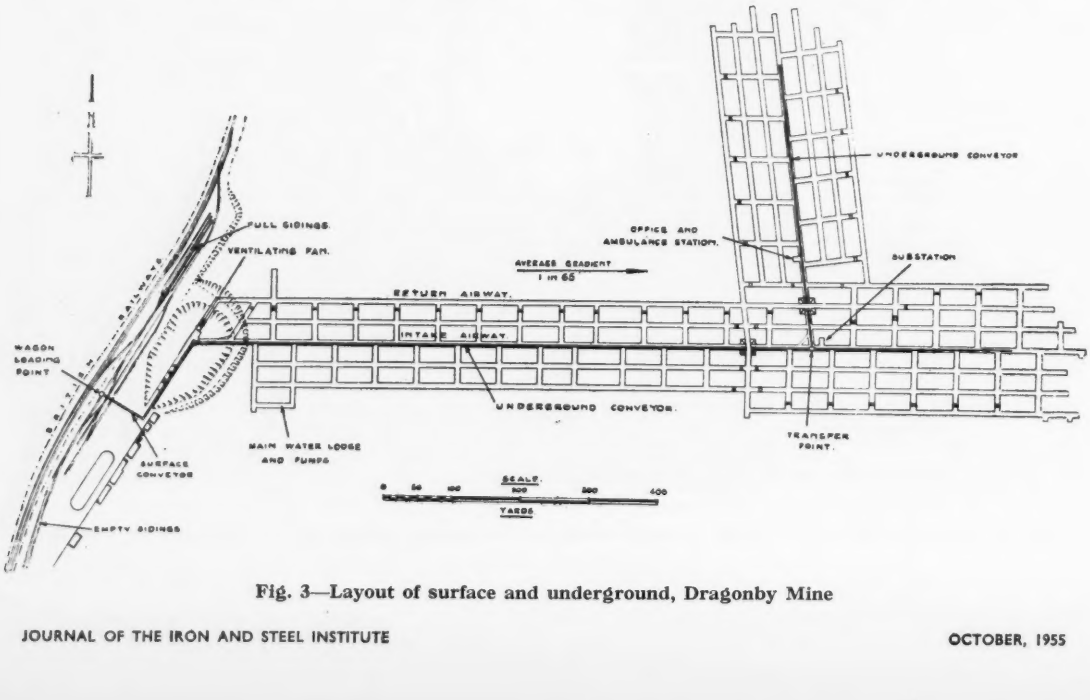


Fig. 3—Layout of surface and underground, Dragonby Mine

trackless mobile machines for preparation and loading, in conjunction with a system of trackless vehicles for transporting the ironstone between working faces and terminal points of a major trunk belt-conveyor system, which would transport the ore along underground arterial roadways and out to the surface, there to discharge direct into 20–30-ton capacity hopper-type ore wagons.

To get a suitable gradient between underground and surface, on which there would be no danger from lumps rolling back along the conveyor, access to the bed had to be made almost at right-angles to the proposed roadways. These were laid out so that five parallel roads on 90-ft. centres running through the area in an easterly direction, when connected by cross-cuts at intervals of 180 ft., would be formed into pillars which would support the roads throughout their useful life. The purpose of the cross-cuts connecting the main roads is to produce ore, to form the pillars, to promote ventilation of the mine, and to serve as transport and communicative links between the roads themselves.

As the roadways advance further into the virgin area, other headings will be turned off to the left and right, which in time will be further connected by other series, and so on until the whole area is cut up into large panels or blocks. When these panels or blocks are being extracted the potential output of the mine will be reached; meanwhile, production comes from the driving of the 20 ft. wide × 18 ft. high development headings.

Figure 3 shows the layout of the surface and underground, and Fig. 4 shows a cross-section of an underground roadway in relation to the bed.

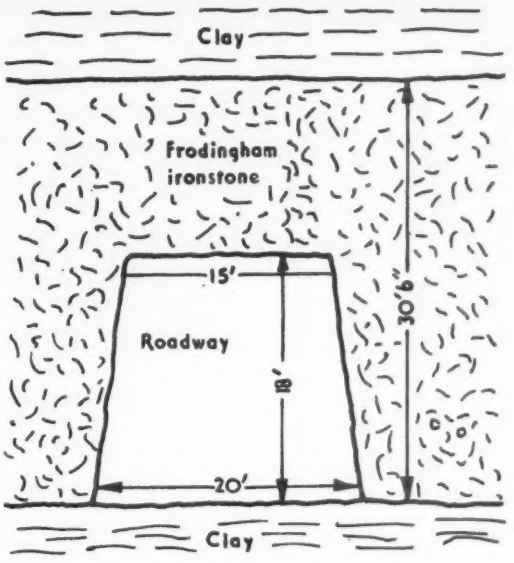


Fig. 4—Cross-section of an underground roadway in relation to the bed

PREPARATION

In March, 1948, civil engineering contractors were entrusted with the work of opening up the bed, forming two initial entries into it, and preparing the surface site for wagon sidings, etc. Using draglines, bulldozers, and lorries they removed 200,000 cu. yd. of sand and clay to bare the bed at the base of a huge excavation in the form of an amphitheatre, or basin, measuring about 500 ft. × 300 ft. across the top and about 65 ft. deep. When this was roughly formed, the ironstone in the bottom was extracted down to the basal clay by light charges of explosives, and loaded out by means of a digger, first into lorries and later by a temporary belt conveyor (*see* Fig. 5). All the material from this excavation, with the exception of the ironstone, was used to bring the surface site for sidings, shops, offices, etc., to the required formation levels. In the excavation was formed an open gullet which, dipping at 1 in 4 from the surface at the southern end, intersects the base of the bed towards the north. It was finished 30 ft. wide with a concrete floor and retaining side walls back-filled with mass concrete to a minimum thickness of 18 in. (*see* Fig. 6). From the side walls the sand and clay overburden were battered back to a gradient of 1 in 2, until they ran out with the natural surface contours; thus the eastern bank is much longer than either the west or the north. Since the angle of repose of clay measures is extremely unpredictable, herring-bone trenches were cut in the clay and filled with rubble to collect and drain the water off the surfaces. These in turn connect with open gullies formed in the concrete back-filling of the side walls, from where the water is conducted away by pipes. Other surface drainage from beyond the periphery of the basin is trapped by a 6-in. dia. open jointed-earthenware pipeline and carried to a main outfall pipe which discharges into a dyke.

In spite of these precautions, unfortunately, weathering of the clay had allowed rain-water to permeate to such an extent that, following the heavy rains of July and August, 1954, a slip occurred near the top of the eastern slope, which slowly encroached and compelled a partial covering-in of the gullet. This had no serious effect on the mine, beyond the loss of two days' production whilst it was got under control.

Whilst the gullet side walls were being completed, two main adit entrances were driven into the bed, one in an easterly direction, and the other northwards for a short distance before turning eastwards parallel to the former. This was done to get the required distance between them, so that after they had been connected by a cross-cut, another parallel heading could go in between to form three, the other two starting from a cross-cut to the right of the former. These are the only adits which connect with the gullet and form, respectively, the main intake airway and conveyor road and the main return airway. The main intake airway was driven about 21 ft. wide × 19 ft. high and supported by a lining of rolled-steel arch girders, 20 ft. × 18 ft., set 2 ft. 6 in. apart and surrounded by reinforced concrete. The main return airway had, at a later date, to house the mine fan, and for this reason it was driven 21 ft. wide × 26 ft. high for the first 60 ft., after which it reduced to the same dimensions as the intake airway. By using

extension rolled-steel joists on the legs of the 20 ft. × 18 ft. arches, the same size served for both purposes. Great care had to be exercised when starting the roads into the hillside, lest blasting might shake and/or uplift the newly exposed clay above, thereby increasing the risk from falls. There were, in fact, one or two uneasy moments during this period, but fortunately nothing of a serious nature happened to hold up the work.

By the end of 1949 materials and plant had begun to arrive on site and sufficient progress been made to permit the erection of the first three conveyors and wagon loading station, and the laying of full and empty reception sidings.

CONVEYORS

The three initial and subsequent conveyors are 48-in. wide belts of 32-oz. 8-ply cotton duck, covered with rubber $\frac{9}{32}$ in. thick on one side and $\frac{3}{32}$ in. thick on the other. They are joined together by splicing the ends into one another and vulcanizing. Carried on a supporting structure of angles and channels by 5-in. dia. troughed idler rollers spaced 2 ft. apart, they run at 200 ft./min. and can deliver at the rate of 400 tons/hr. Conveyor No. 1, between the wagon loading station and the top of the gullet, is a fixed length of 220 ft. and has a 30-h.p. motor. Conveyor No. 2, operating on the 1 in 4 gradient, is a fixed length of 420 ft. and originally had a 60-h.p. motor with an electric brake. As time went on this was found to be insufficient and it has recently been replaced by one of 75 h.p. with the inclusion of a Vulcan–Sinclair fluid coupling, placed between it and the gear box, together with a modified braking system. The former permits a smooth getaway after the conveyor has been standing and the latter, in addition to preventing a run-back when the belt is stopped under full-load conditions, allows the motor on restarting to get up to speed before disengaging by the incorporation of a 2–3-sec. sequence delay. This combination is a big improvement and has completely eliminated any hesitancy or snatching of the conveyor when being restarted.

Conveyor No. 3 (*see* Fig. 7), when first installed along the main intake airway, was 30 yd. long and differed from Nos. 1 and 2 in that it was not designed for a fixed length, but was to be extended from time to time as the headings advanced, until it reached a maximum distance of 1000 yd. For this duty a 75-h.p. motor was provided. Actually the conveyor was terminated at 900 yd.; although it has not given any trouble, it is to have a fluid coupling installed to meet the higher tonnages.

LOADING STATION

The wagon loading station, which also houses the driving gear for No. 1 conveyor, is designed to load both 20- and 30-ton capacity hopper-type ore wagons of standard track gauge. To prevent spillage during wagon changing operations, a transporting breeches chute is provided which deflects the ironstone from the side-discharging conveyor at right-angles, so that the wagons are end-filled. This results in better filling and enables the ' loader man ' to avoid overfilling and, consequently, spillage.

Siding accommodation is provided for 70 full and 40 empties. These are usually brought to the mine in trains of 34 by one of the Company's own locomotives, which places them in the cul-de-sac sidings above the loading house. From here they gravitate back and are uncoupled into sets of six by a wagon attendant, ready for handling by a spotting mule. This is a small 10-h.p. electric winch which operates an endless rope to which is attached a ' mule ' mounted on a narrow-gauge track laid in the centre of the permanent way. By remote control the loader man can engage the axle of any wagon and move it as required. General practice is that while the fifth wagon of a set is being filled, another set is being engaged ready for ' breasting ' through. As a set of fulls pass from the loading point they are engaged by the wagon attendant who takes them on brakes into the sidings. Normally the wagon attendant and loader man keep the job going, but occasionally during peak periods assistance is given by a third man.

DEVELOPMENT

These installations were completed by August, 1950, when the Company's own men made a start as a small production team to drive the headings forward, using the first machinery and equipment which had been received during the interval. During the first week about 400 tons of ironstone was produced and, with the introduction of further equipment and by improving operational technique, this was increased to almost 4000 tons per week. After the five main headings with their connecting cross-cuts had been driven 900 yd., another series was commenced in a northerly direction and equipped with new machines of a second production set-up. To cater for this No. 3 conveyor was terminated and a 20-ton capacity surge bunker with a variable-speed plate feeder was installed (*see* Figs. 8 and 9). Into this now delivers the new east district tandem conveyor (*see* Fig. 10) and the north district conveyor, each of which is 400 yd. long.

To give better scope for preparation and production in the two districts beyond this point, the number of headings in each was increased from five to seven. Since the second district went into production weekly outputs in excess of 8000 tons are obtained by single-shift loading over five days.

Conveyors are extended every 100 yd., which is the maximum distance which can be comfortably managed over a normal weekend, and which meets the requirements of the battery-operated secondary transport vehicles. Normally, stopping and starting is done by automatic sequence control from fixed points, but in case of emergency this can be done from anywhere along their length.

To ensure a smooth passage of the ironstone from one conveyor to another, suitable transfer stations with chutes are provided, and to reduce the shock and belt damage to a minimum the normal steel troughed idlers underneath the chutes are replaced by special thick rubber-cushioned ones. To prevent ' belt float,' which was caused by wet clay adhering to the bottom rollers, it has been found beneficial to spray the belt while running with as much water as

Fig. 5—Ironstone being removed to basal clay

Fig. 6—Completed gullet

Fig. 7—Part of No. 3 conveyor

Fig. 8—Plate feeder delivering on to No. 3 conveyor

Fig. 9—20-ton surge bunker with plate feeder

Fig. 10—East district tandem conveyor driving gear

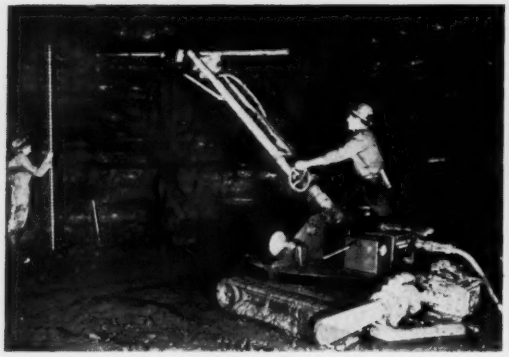


Fig. 11—Shot-hole drilling machine

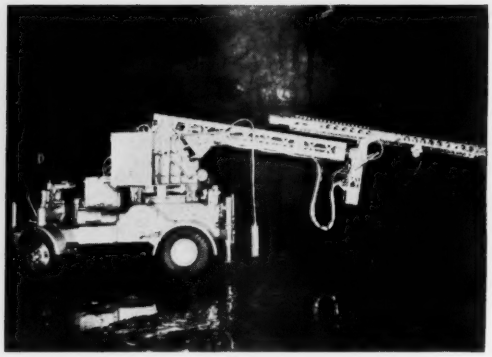


Fig. 12—Hydro-electric drilling machine

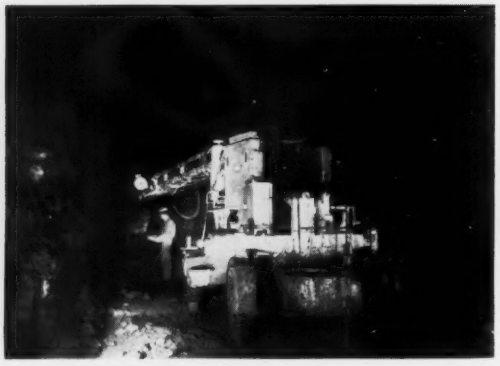


Fig. 13—Operator locating new hole position at the face

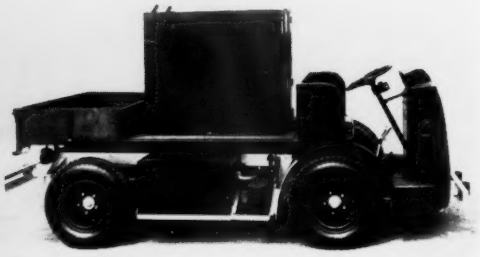
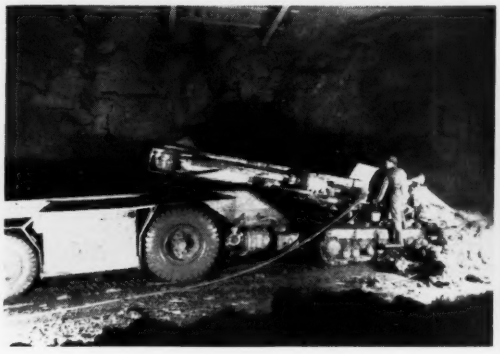


Fig. 14—Battery-driven vehicle for transporting explosives

Fig. 15—Trimming by means of pneumatic pick

Fig. 16—Mobile battery-driven vehicle for roof maintenance

(*a*)



(*b*)

Fig. 17—Loading machine discharging into (*a*) 60*D* shuttle car, (*b*) main belt

Fig. 18—Pulsometer pump installation

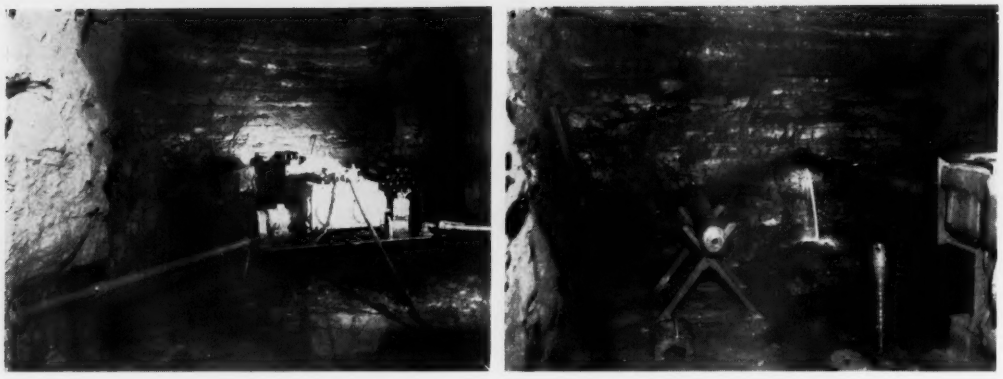


Fig. 19—Wallram bore-drilling machine in use for pre-draining

Fig. 20—Interior of main surface substation

Fig. 21—Typical charging station

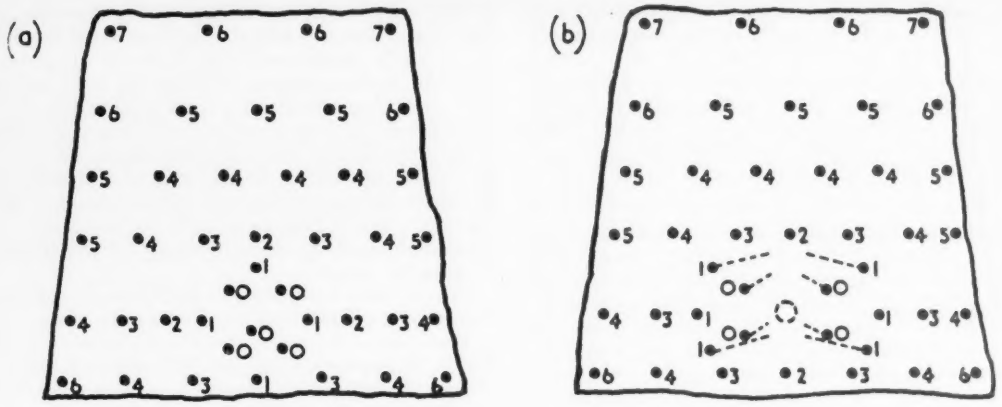


Fig. 22—Patterns of drilling holes at (*a*) north district, (*b*) east district

experience and circumstances dictate, and then plough the whole lot off at some convenient place where it can be handled. It is not suggested that this is a cure for all ' belt float ' troubles, but it has solved the particular problem at Dragonby.

MINING METHODS

The sequence of production operations at the face of the heading is: drilling, charging with explosives, firing, trimming roof and sides, and loading out; these are done to a carefully planned cycle throughout the day, as follows:

Drilling, charging, and trimming: Two shifts per day (6 A.M.–2 P.M.; 2 P.M.–10 P.M.)
Loading out: One shift per day (8 A.M.–4 P.M.)
Firing: One shift per day (10 P.M.–6 A.M.)

Drilling

Up to 12 months ago all shot holes were drilled by machines of the type shown in Fig. 11, but today 80% are drilled by modern hydro-electric machines, like the one shown in Fig. 12. In addition to being able to drill holes vertically up or down, these machines can drill at any angle within an area 24 ft. wide × 18 ft. high. Briefly, they consist of a pressed-steel drilling frame which is attached to a main box-shaped boom by means of trunnions, about which point it can be moved by two hydraulic cylinders. In addition it can rotate about the boom. The main boom, which is mounted on a turntable, can be raised or lowered by a main hydraulic jack and can also be extended by means of an internal hydraulic cylinder. The 6-h.p. drill motor remains in a fixed position at the rear end of the drilling frame, whilst actual rotation and propulsion of the drilling rod is done by means of a travelling gearbox. Traction, at 1½ m.p.h., is done by a 10-h.p. motor with integral gear box through a standard Ford 3-ton differential axle and Reynolds chain. A special feature is the high ground clearance, the traction motor and driving axle being more than 3 ft. from ground level.

One man operates the machine, every movement of which, apart from traction, he is able to make from a portable push-button panel. When fitted up with an 11-ft. long spiral drill rod and a tungsten-carbide-tipped bit, it can drill a $1\frac{11}{16}$-in. dia. hole at a constant penetration speed of 4 ft./min., and automatically retracts at 47 ft./min. on reaching the required depth of 10 ft. In the north district 44 parallel holes, 10 ft. deep, are drilled horizontally to a set pattern which includes six in the lower centre, which are termed the ' burn '; in the east district, however, where the ' Wallram ' hole (described later) takes the place of the burn, 43 are drilled—35 parallel and the remaining 8 to a wedge pattern. A full round of shot holes therefore involves 430–440 ft. of drilling, which normally takes about 2½ hr. As each heading is completed the machine is flitted into another. Figure 13 shows the operator locating a new hole position at the face and Figs. 22*a* and *b* show the two patterns he may be working to.

Charging and Blasting

Charging a heading occupies about the same time as drilling and is always done by a trained and qualified person, appointed for that purpose and assisted by another man. They get their supplies of explosives, 900 lb. at a time, from the surface magazine by means of a specially designed battery-driven vehicle (Fig. 14) which can be taken to each heading as it is about to be charged.

In the north district, where the burn pattern is used, 42 holes are charged using about 153 lb. of explosive. The two holes drilled close together in the centre of the burn are left uncharged. Instantaneous and ½-sec. gasless delay detonators are used in such an order as to form an initial cavity round the burn, towards which the rest of the charges blow in their allotted sequence.

The method of charging in the east district, where the Wallram hole is pre-drilled well in advance, is slightly different. In this case all 43 holes are charged, using about 144 lb. of explosive. By firing the wedge holes first, the initial cavity already existing is rapidly enlarged and relieves the remainder of the charge. Experiments in blasting with a Wallram hole are still continuing; so far results have shown a more consistent depth of ' pull ' (advance) with better fragmentation.

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To meet present-day outputs, approximately nine headings have to be prepared in this way each day. They are all blasted on the night shift, when there is a minimum of personnel underground, and when the smoke and fumes have time to clear away before the men start work next morning. Each heading, when blasted, produces approximately 200 tons.

Trimming

This is done by small specialized crews who, under the watchful eye of the deputy (official), ensure that each heading is made safe for further work following blasting, by taking down all loose material from the roof and sides. Figure 15 shows a man doing this with the aid of a pneumatic pick. The roof is generally good and normally self-supporting, but there are occasions when, owing to the lens-like structure of the deposit, the roof strata change, when either more than is required must be taken down or the roof must be held up by supports. Generally it is preferred to keep roof levels uniform if possible. Consequently, these places when found are supported. There is an important reason for this: if undue ' corrugating ' of the roof is permitted, the atmosphere is allowed to enter the strata and increase the risk from falls. The supports are almost always long straight rolled-steel girders; these are fastened either by socketing into the solid sides or by resting on steel dowels, let into holes drilled into the sides, wood packing being placed in the cavity between the girder and the roof.

To assist with this work a 72-h.p. electrically driven mobile air compressor is provided. In addition to the care of the roof at the working face, it is essential that regular routine examination should be carried out along all roadways; to do this properly a special mobile battery-driven vehicle is used. It carries two hydraulically operated lifting towers, one with a revolving platform for men to work on, and the other with facilities for raising girders to roof height. Power for the hydraulics is derived from a 10-h.p. motor taking its supply from the 96-V. batteries. With this self-contained unit a skilled ' roof crew ' can get almost anywhere, as shown by Fig. 16 (note how the forward hydraulic tower has lifted the girder to the roof).

Loading and Mobile Transport

The machines used for loading and the mobile vehicles for transporting are called, respectively, ' joy loaders ' and ' shuttle cars.' Weighing almost 17 tons and standing about 6 ft. high, the 18*HR*2 rock-loading machine is the largest and most robust in a range of gathering-arm-type loaders. It employs a tractor-mounted main chassis for mobility and carries a chain conveyor, the front end of which is built into a wedge-shaped blade, known as the ' gathering head.' Mounted on this blade are two arms, one on either side of the chain conveyor, which actuates through an arc in a particular sweeping and gathering motion, and gathers the prepared ironstone from the pile, feeding it on to the chain conveyor. This transfers it to the tail or discharge end of the loader, which is arranged to swivel through 45° on either side of the centre-line, in addition to being elevated or lowered to meet the loading requirements of the transporting vehicle. By using hydraulics and adjustable pre-loaded clutches, the machine is given great flexibility and is easily manœuvrable at all stages. It is driven by four electric motors, totalling 94 h.p., and the operator, when standing on the footplate attached to the machine, has complete control of every movement through a bank of controls conveniently placed. It is capable of loading at the rate of 6–8 tons/min., but interruptions in the supply of transport (e.g. whilst changing shuttle cars over) reduces this filling rate. It is most seriously affected during flitting from one heading to another.

To overcome this otherwise fluctuating output, each district is provided with two loading machines, which enables one to be loading out whilst the other is being flitted, its cables re-arranged, etc., and made ready at a new pile. In this way it is quite possible to maintain uniform outputs and give the machines the daily maintenance they require. The best result obtained from two machines, in a normal productive week of 40 hr., is 9475 tons.

The shuttle cars which transport the ironstone between the loaders and the main belt-conveyor system are really mobile hoppers of 10–12 tons capacity, mounted on four massive rubber-tyred wheels, one pair of which are driven by two 7½-h.p. D.C. traction motors taking their supply from a 48-cell 96-V. 600-A.hr. battery split into two equal parts so that they can conveniently be carried along their sides within the wheels. Along the bottom of the car (i.e. on the carrying deck) is a chain conveyor driven by another 7½-h.p. D.C. high-torque motor and used for loading and unloading purposes. The driver's position is at one corner of the vehicle, where dual controls and seats are provided on either side of a swivelling steering column, thus enabling him always to face the direction in which he is travelling. Their speed varies between 2½–3 m.p.h. when full and 4 m.p.h. when empty. Usually three serve one loader, which they can do very well for a shift without a battery change, provided that the running distances are not excessive and the floor of the roadways is kept reasonably clean. Battery discharge is affected as much by heavy going and cloggy road conditions as it is by distances.

Upon reaching the main conveyor system, each car, after running up a portable steel ramp, discharges its load of 10–11 tons direct on to the rubber belt by means of the internal conveyor in about 1½ min.

Figure 17*a* shows a loading machine discharging into a 60*D* shuttle car, and Fig. 17*b* the same vehicle discharging its load on to the main belt.

VENTILATION

For a time, after the initial entries had been connected, natural ventilation sufficed, but as it is essential in underground mining to maintain a constant circulation of fresh air throughout the workings, a 60-in. dia. single-inlet torpedo fan was installed. This is housed at the entrance to the main return airway at the bottom of the gullet, its evasee being just behind the north wall. Driven by a 10-h.p. 720-r.p.m. motor through four tex-ropes and pulleys, giving a reduction in speed of 2½ to 1, it exhausts at present

about 28,000 cu. ft./min. at 0·1 in. W.G., but by increasing the power and speed it is capable of passing up to 70,000 cu. ft./min. By replacing the present axial-rotor by one of a new design, quantities in excess of this are possible.

Coursing the ventilation round the mine is done by erecting breeze-block stoppings, doors, and regulators across certain roadways, and by constructing overcasts or air crossings at selected points. To comply with statutory requirements samples of the air are collected from a number of points along the circuit at regular intervals and are afterwards analysed.

WATER

It was anticipated from the beginning that water would have to be dealt with, and as it might come from the exposed outcrop face as well as from the mine development, early provision was made to deal with it by making a main lodge just inside the mine. This is equipped with two 55-h.p. single-stage Pulsometer pumps capable of dealing with 40,000 gal./hr. As normal requirements are about 15,000 gal./hr. only one pump is normally run, the other acting as standby. Figure 18 shows this installation.

Almost all the water dealt with comes from some of the hundreds of shot holes which are drilled into the working face each day. The water is not, however, held in the bed itself like a sponge, but is contained and withheld in ' fissures ' or ' breaks ' which vary considerably in frequency, width, and extent. Some are therefore capable of holding copious volumes, which, whilst running off, become a nuisance if proper face-pumping facilities are not maintained. To try to draw the water from these ' artesian ' reservoirs to one point in each heading or, if possible, to one heading, as well as to improve blasting, a Wallram wide bore-drilling machine was obtained last year. With this machine an $8\frac{1}{4}$-in. dia. hole is drilled up to 100 ft. in advance of every heading in the east district. As the fissures generally run in a N.W.–S.E. direction, one or more of the holes intersect them and pre-drain the water, thus allowing the headings to advance in much drier conditions than would otherwise be possible. This has been most noticeable in one heading, where Wallram holes have tapped water up to 200 gal./min.; this has not run off completely until after several weeks. To develop this further it is hoped in the future to pre-drain much larger areas by drilling holes up to 200 ft. deep. Figures 19*a* and *b* show the machine at work.

Normal practice for pumping is to have one 80-gal./min. semi-portable pump in each heading of the east district, with two in the north district, all of which deliver into catchment lodges or tanks. It is delivered from these catchment places through 6-in. dia. rising mains to the main lodge by high-capacity centrifugal pumps.

POWER SUPPLY AND DISTRIBUTION

Electric power at 6600 V., 3 phase, 50 cycles, is received at the surface substation (Fig. 20) via overhead lines from the Appleby-Frodingham Steel Works, and is stepped down by 400- and 750-kVA. transformers to 400–440 and 3300 V., respectively. The former, through a distribution panel, supplies the surface shops, Nos. 1, 2, and 3 conveyors, the wagon spotting winch, the mine fan, and the main underground pumps; the latter supplies everything else underground, through a 0·1-in. 3-core, P.I.L.C., D.W.A., H.T. cable, running along the main conveyor road to the north district junction, where it enters a substation containing three main oil-immersed breakers and a 150-kVA. transwitch unit. From two of the switches a supply is fed into the north and east districts, the other switch and the transwitch unit serving the north and east district conveyors and the plate feeder. Conveniently situated in the north district are two transwitch units of 100 and 150 kVA., the former serving a battery charging station for the mobile transport vehicles, and the latter two banks of gate end switches located a safe distance away from the working faces. These switches are of standard mining design and embody earth-leakage protection, pilot circuit for remote control, no-volt coils, and overload coils, which are set to safeguard each individual mobile machine from serious damage.

As the various machines move from one heading to another they obtain their supply from the nearest bank of switches by means of 200-yd., 0·04-in., 5-core, collectively screened, trailing cables. The east district arrangements are exactly the same as the north, except that both transwitch units are 150 kVA., owing to the provision of an additional mobile air compressor. In an emergency the mine ventilating fan and main underground pumps could be run by power supplied from an auxiliary 100-kVA. Diesel-driven alternator on the surface. This is tested once a month.

The aggregate electrical horsepower of the whole mine is 1258 and the maximum demand, taken over half-hourly periods, is 420 kW. For an output of almost 200,000 tons during 24 working weeks, the electrical units consumed averaged 4·2 per ton.

LIGHTING

In addition to the Nife portable miners' electric cap lamps, which each underground worker carries, the main conveyor roads are illuminated throughout their entire length by 60–65-W. sodium-vapour vertical-burning lamps, fitted with prismatic glass-mirror reflectors, and spaced approximately 90 ft. apart at roof height.

ELECTRIC BATTERY CHARGING

Battery charging is carried out at a central point, a reasonable distance back from the face in each district, and where a current of fresh air can pass through the station directly into the return airway. As each 60*D* car battery weighs approximately 30 cwt., stations are equipped with overhead girders for traversing chain lifting blocks and light steel-framed roller conveyors to facilitate their side movement during changing. This can be done in 20 min. Figure 21 shows a typical charging station.

Charging is done whilst the batteries are standing on the roller conveyors, by means of one automatically controlled Solenium metal rectifier to each pair of batteries. The period of charging varies according to

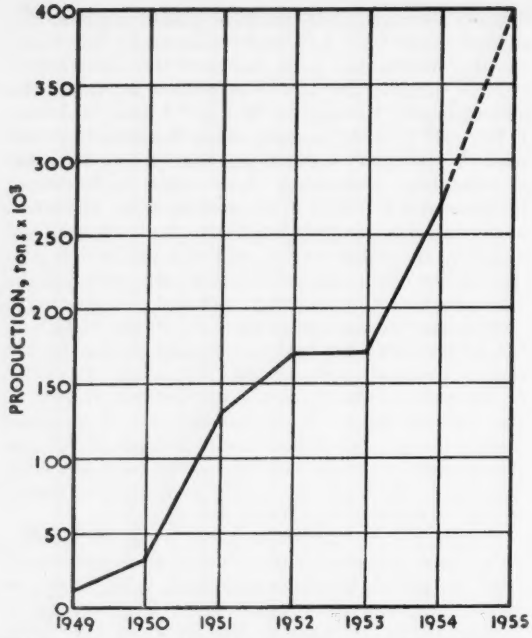


Fig. 23—Annual tonnages produced since the mine was started in 1949

the condition of the batteries, but usually they require 7–7½ hr., with a maximum of 10 hr.

MAINTENANCE

In addition to the machines and equipment described in this paper there are, of necessity, other items of ancillaries (e.g. trackless stores-supplies vehicle, bulldozer, 5-ton lorry, etc.) which play just as important a part in the day-to-day working. To withstand the rigours of underground mining, all of these must be examined regularly and generally maintained in good working condition. Underground facilities for this are provided in a workshop complete with benches, vices, drilling machines, etc., where the staff of skilled mechanics and electricians not only do the routine jobs but can also work wonders in an emergency.

SAFETY, HEALTH, AND WELFARE

Every precaution is taken in the interest of safety and health, and much is done for the welfare of the men, including, for example, such things as providing them with safety helmets, protective clothing where required, gum boots, etc. There are snap cabins underground, where hot-water boilers enable them to enjoy freshly made tea with meals eaten in reasonable comfort. On the surface there are changing rooms, provided with heated clothes-lockers for each individual, and washing facilities, so that the men can come and go away clean and respectably dressed.

MANPOWER

The following table shows the deployment of manpower in August, 1955:

Underground	
Drilling	12
Shotfiring and assistant	5
Trimming and supporting	20
Loading and flitting	4
Shuttle cars	9
Conveyor attendants and clean-up	3
Pumps and settling tanks	7
Other underground labourers	18
Electrical and mechanical maintenance	15
Officials	6
	99
Surface	
Electrical and mechanical maintenance	4
Loading and labourers, lamp cabin, stores, etc.	17
Total	120

A problem present from the inception of the mine was the recruitment of labour suitable for training to use the mechanized equipment, and also the selection of men suitable for training as officials. These difficulties have gradually been overcome and the present personnel, largely obtained from men without previous knowledge of such work, are very satisfactory; this suggests that the staff needed for further increases in output will be forthcoming. This means that, through the years, the occupation will grow and spread until it becomes deep-rooted amongst the important industries of Scunthorpe.

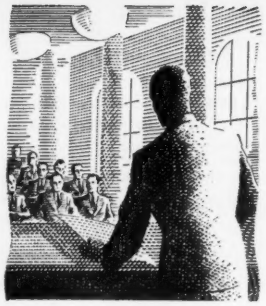
OUTPUTS

Figure 23 shows graphically the annual tonnages produced since the commencement of the mine, the figure for 1955 being forecast according to the position at the time of writing. The increase during 1954 was due to the introduction of the second production unit as a result of starting to work the north district headings and the installation of the additional conveyors.

With what is already planned, it is hoped to raise the output of the mine next year (1956) to over 500,000 tons, i.e. over 50% of the output eventually planned.

CONCLUSION

In conclusion it can be said, with confidence, that sufficient experience has already been gained to prove that underground mining of the ironstone in the Frodingham bed can be carried out successfully.



DISCUSSION ON PAPERS

Discussion at Meetings · Written Contributions

AUTUMN GENERAL MEETING, 1954

The AUTUMN GENERAL MEETING of THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 17th and 18th November, 1954, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, the Hon. R. G. LYTTELTON, was in the Chair.

Morning and afternoon sessions were held on both days, and a report of one of the sessions is printed below. The remainder will be published in later issues of the *Journal*.

DISCUSSION ON REHEATING FURNACES

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parentheses):

" An Investigation of Reheating Furnace Design and Performance," *by F. A. Gray and S. H. Brooks* (1954, vol. 178, Nov., pp. 223–266).

" Internal Temperature Distribution in the Cooling and Reheating of Steel Ingots," *by R. J. Sarjant and M. R. Slack* (1954, vol. 177, Aug., pp. 428–444).

In presenting his paper, Mr. **F. A. Gray** (United Steel Companies Ltd.) made the following corrections to certain diagrams:

Fig. 9: In the key, the words ' Not on time basis ' should not refer to the ' optical readings on test billet.'

Fig. 21: In the scale of ' Roof pressure changes, in. W.G.' the fifth value from the left should read ' 0·038 ' and not ' 0·838.'

Fig. 25: The lower scale should read ' Air/gas ratio, arbitrary units (× 0·76 to give in cu. ft./cu. ft.).'

Fig. 29: In the key, the lines marked ' 2 ' and ' 3 ' should refer to positions 3 and 5, respectively.

The second paper was presented by Professor **R. J. Sarjant** (University of Sheffield) and Dr. **M. R. Slack** (English Electric Co., Ltd.).

Mr. **H. Southern** (G. P. Wincott Ltd.): The paper by Mr. Gray and Mr. Brooks is unique because it presents, in greater detail than any previously published work, the operating characteristics of a large continuous reheating furnace. It is of particular interest to me because it relates to a furnace which is similar in size, type, and capacity to one built during the period of the first World War, when I worked upon the erection of three of the earliest Morgan continuous rolling mills to be installed in the U.K.

The paper brings to light a most interesting fact. It clearly shows that it was not impossible, even more than 35 years ago, to build a furnace which is still capable of operating at a thermal efficiency of 50%. The attainment of such a degree of efficiency does not, however, arise from unique or special features in the design and construction of the furnace but rather from its continuity of operation under full load conditions.

The particular furnace described by the authors has a hearth 40 ft. long × 32 ft. wide and they rate its capacity at 40 tons/hr. With a hearth utilization of 94%, which corresponds to the charging of 30-ft. billets, the optimum capacity of the furnace is perhaps nearer 30 tons/hr. The hourly rate of thermal transmission to the billets would then be about 20,000 B.Th.U. per sq. ft. of heat-receiving surface.

During the tests the authors used 45 instruments to measure 80 variables and collected most valuable information. Figure 9 shows an almost linear relationship between steel temperature and time after charging, and it would be interesting to know if a rise of 15 C. deg./ min.

is typical of all tests. Figures 11*a* and *b* show normal expectancy between gas flow and rolling rate and clearly indicate the influence of thicker billets upon fuel consumption. Figure 13 shows that the waste-gas temperature increases with output and therefore supports a widely held opinion, but are the authors satisfied about the linear relationship ?

On the question of furnace pressure, the authors first assumed that 0·04 in. W.G. was the correct pressure to use to bring the zero-pressure line down to the mean height of the chamber. This assumption was presumably based upon the desire, and indeed the necessity, to achieve a compromise between air infiltration and the blow-out of hot gases. The line of zero pressure should, of course, be at the sill level of the discharge doors, but the authors found that it was impossible to achieve this condition. This is not at all surprising because the contour of the furnace, in the longitudinal cross-section, is open to criticism.

A slope of 1 in 7 in the hearth of a furnace 44 ft. long is conducive to air infiltration if the waste-gas ports are incorrectly located. It is also conducive to the blow-out of hot gases, a condition which is further aggravated by an upward rising roof.

The authors' tests show that the blow-out of hot gases averaged 27½% of the total products of combustion and that air infiltration simultaneously occurred at the discharge doors, a result which causes no surprise. It is therefore regrettable that the painstaking efforts of the authors, in collecting such a wealth of data, were expended on this particular furnace.

In the authors' consideration of thermal transfer to the stock they compare their findings with the empiricisms of Schack and Heiligenstaedt. It is not, however, wise to accept empirical data too blindly because much work has still to be done on heat transfer in industrial furnaces. Table V summarizes the results obtained in seven particular tests. What do the data under the heading ' Heat Output ' show and could they have been predicted by an experienced furnace designer ?

There are one or two fundamental relationships, still not widely known, which exist in relation to all furnaces and these can be simply expressed. The heat utilized within a furnace chamber of the simplest type is absorbed by the steel and the walls. Hence, if

H_S = Heat absorbed by steel
W_L = Heat absorbed and dissipated by walls
H_G = Heat content of outgoing waste gases
Q = Units of fuel consumed
h_f = Lower calorific value of fuel per unit
n = Thermal efficiency of furnace
ϕ = Factor of heat utilization,

then
$$\frac{H_S + W_L}{Q \cdot h_f} = \frac{n}{\phi}$$
$$\frac{W_L}{Q \cdot h_f} = \frac{n}{\phi} - n$$
$$\frac{H_S}{Q \cdot h_f} = n$$
and
$$\frac{H_G}{Q \cdot h_f} = 1 - \frac{n}{\phi}.$$

Mr. Gray and Mr. Brooks show that the thermal efficiency of the furnace they tested is about 50%, so $n = 0{\cdot}5$.

Experienced furnace designers know, however, that ϕ rarely exceeds 0·8, even in the most efficient continuous reheating furnaces, and so, accepting this figure,

$$\frac{n}{\phi} = \frac{0{\cdot}5}{0{\cdot}8} = 0{\cdot}625$$
$$\frac{n}{\phi} - n = 0{\cdot}625 - 0{\cdot}5 = 0{\cdot}125$$
$$n = 0{\cdot}5$$

and
$$1 - \frac{n}{\phi} = 1 - 0{\cdot}625 = 0{\cdot}375.$$

These figures therefore indicate the results that could have been predicted, and they are repeated below in relation to the authors' figures for test 1 :

	Authors' Figures	Estimated
Heat to steel	50·71	50·00
Waste gas to recuperator	16·66	37·50
Blow-out gas	17·75	
Cooling water	2·08	12·50
Structural losses	12·80	
	100·00	100·00

Dr. **P. H. Price** (Sheffield University): Figure 20 in the paper by Professor Sarjant and Dr. Slack applies not only to this particular soaking pit but in general. If efficiency is plotted against rate of heat utilization divided by the number of square feet of heating surface, the result is a straight line passing through the origin, as shown in that graph. That can be expressed as:

$$\text{Efficiency} = \text{Constant} \times \frac{\text{Rate of heat utilization}}{\text{Heating surface}}$$

The efficiency itself is

$$\frac{\text{Rate of heat utilization}}{\text{Rate of heat input}}.$$

' Rate of heat utilization,' which is in the numerator on both sides of the equation, cancels out; since everything of interest is now in the denominator, the equation is more conveniently expressed as:

$$\text{Rate of heat input} = \frac{1}{k} \times \text{sq. ft. of radiant heating surface},$$

where $\frac{1}{k}$ is a constant.

Roughly, that means that for a bigger furnace more heat is put in, but it also shows that the amount of heat put in is proportional to something like the wall area of the furnace and not the volume of the furnace.

The type of calculation which Dr. Slack undertook is very long and tedious, and so many people find it very easy to borrow the results of the calculations which exist in the literature, forgetting that perhaps the conditions at the surfaces of their ingots and moulds are a little different. Having borrowed these results, they may find that they do not agree with their own works practice, and so they say that numerical methods are useless. If, however, they use their own surface or boundary conditions, and apply these methods, or possibly yet more accurate methods which are still being developed by Mr. Siddall at Sheffield University, they may find that they have some agreement. For a given surface thermal history, the calculation, although tedious, need be performed only once. Thus it is not unreasonable for a works to perform such a calculation, with a surface condition suited to its own practice.

Mr. **R. G. Siddall** (Sheffield University): I am doing some similar numerical analysis on 15-ton ingots, and have also encountered the difficulty of dealing with the calculations for the first 5 min. after teeming. The main difficulty is that conduction and radiation are taking place at the ingot/mould interface. It is impossible to allow for both these phenomena simultaneously in a numerical calculation, as conduction implies two surfaces at the same temperature and radiation two surfaces at different temperatures. The two approximations to the boundary heat flux made by Dr. Slack are

(i) Instantaneous overall separation of the ingot from mould on teeming, and radiation thereafter
(ii) Conduction for the first 3 min. after teeming, then instantaneous overall separation followed by radiation.

On applying these assumptions to the 15-ton ingot large discrepancies are found between the temperatures measured by Mr. L. H. Savage of B.I.S.R.A. and those calculated. This implies that there will be large errors in the calculated steel temperature for this period, although no satisfactory measurements are available to verify the fact.

In order to obtain agreement with the measured mould temperature I have found it necessary to assume instantaneous separation on teeming and radiation flux with an emissivity which is at first artificially high (about 1·5) and then falls to a value of about 0·5 over the first 4 min., remaining at this value thereafter. Such a method allows approximately for both conduction and radiation, and shows the gradual nature of separation (*i.e.*, decrease in conduction and thus in heat flux) during the first 4 min.

This new method of approximating to the boundary heat flux should give accurate temperature values from teeming time onwards, and not just at the time of stripping.

Dr. **A. V. Brancker** (Aluminium Laboratories Ltd.): The problem of temperature distributions in both static and continuous casting processes is one of practical importance, which has been studied by many prominent scientists. Professor Sarjant, of course, is an authority on this subject, and this particular paper by him and Dr. Slack is of the high standard expected.

That the problem is still not completely solved is due not to lack of ingenuity on the part of these and other authorities but to the complexities encountered and a lack of thermal data over an extensive range of temperatures. This applies particularly to theoretical studies of the continuous-casting process where little information on heat-transfer rates for spray chilling is available.

The partial differential equation for heat conduction in three dimensions x, y, z has the form*

$$C\rho\partial T/\partial t = k[\partial^2 T/\partial x^2 + \partial^2 T/\partial y^2 + \partial^2 T/\partial z^2] \quad \ldots\ldots(1)$$

where $\alpha = k/C\rho$

Assuming α is constant, a formal solution based on two dimensions x, y is given by

$$(T - T_0)/(T_m - T_0) = \sum_0^\infty e^{-\alpha t\beta_s^2/a^2} \cos(\beta x/a) \left[\frac{2\sin\beta}{\beta\left(1+\frac{\sin 2\beta}{2\beta}\right)}\right] \ldots(2)$$

where

$$ha/k = \beta\tan\beta \ldots\ldots(3)$$

and β_s are roots of the transcendental equation (3).

This solution is based on Newton's law of cooling

$$-k\partial T/\partial x = h(T_s - T_0) \quad \ldots\ldots(4)$$
$$x \to a$$

where T_0 is a constant cooling temperature and T_s is a surface temperature varying with y: at best this law may only be an approximation.

In the continuous casting process equation (1) becomes

$$\frac{v}{\alpha}\frac{\partial T}{\partial y} = \partial^2 T/\partial x^2 + \partial^2 T/\partial y^2 + \partial^2 T/\partial z^2 \quad \ldots\ldots(5)$$

In this case, the latent heat source (a constant) is located on a stationary solidification front and the solid moves at a constant casting speed v. If in the static case the solidification front is assumed to move upwards from the bottom plate at a constant speed v, equation (5) may possibly apply, but the left-hand side would have a negative sign.

The only difference in the formal solutions of equations (1) and (5) is that the term

$$\alpha t\beta^2/a^2 \quad \ldots\ldots(6)$$

is replaced by

$$vy/2\alpha + y[(v/\alpha)^2 + 4(\beta/a)^2]^{\frac{1}{2}}2 \quad \ldots\ldots(7)$$

where $v = y/t$.

Equation (7) can, of course, be simplified by approximations. It will be observed that equations (1) and (5) do not contain the latent heat, but when these solutions are presented in the form of standard graphs based on dimensionless groups, latent heat and superheat converted to an equivalent temperature can be contained in T_m, or T_m is the solidification temperature plus these two equivalent temperatures.

The application of these formal equations or standard charts to a steel cooling process will fail if the thermal properties vary profoundly with temperatures. In such cases the method given by Professor Sarjant and Dr. Slack offers a solution of some practical importance, and warrants the labour involved. Keeping in mind the complex nature of the formal solutions it is difficult to accept the simple relationship

$$d \equiv x = b\sqrt{(\alpha t)}$$

given in the paper. Mathematical justification for this equation is claimed and from such authority must needs be accepted. If, however, this equation defines a skin thickness related to a solidification front, it may hold for a parabolic contour but can hardly be a general definition of the profile. The authors can no doubt remove what may be my misinterpretation of this equation or its significance.

In the continuous casting of aluminium alloys (ingots and billets) the thermal diffusivity is fairly constant over an extensive range of temperatures. With an assumption of constant thermal conductivity k, standard charts based on equation (2) modified by equation (7) have been developed which by adjustment in h reproduce experimental data fairly well; temperatures in such cases can be calculated by slide rule.

The method of Professor Sarjant and Dr. Slack merits application to this moving system also, but if the labour involved can be reduced and dimensionless groups or similar can be introduced practice would be well served.

Finally, a knowledge of temperature distributions is the first step in the evaluation of thermal stresses, and the paper, if applied extensively to different systems, may well yield information on the mechanism, magnitude, and distribution of such stresses in the elastic zone.

Dr. **D. Smith** (Sheffield University): In the detailed items of the heat balances in Table V of Gray and Brooks' paper, the magnitude of the wall-loss terms is generally low. In certain cases it is as low as 6% and the blow-out loss is in some cases four times as large. Do the authors believe this? Is agreement obtained when the wall losses are calculated from the thermal conductivity and the inside wall temperature? Our

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* C = Specific heat
ρ = Density
α = Thermal diffusivity
k = Thermal conductivity
h = Heat-transfer coefficient
t = Time
T = Temp. at position of co-ordinates x, y
a = Length of side
x = Position on a
T_m = Solidification temperature
T_0 = Chilling temperature
$\beta = (u\pi)/2$
u = Constant included in solution of eq. (2)

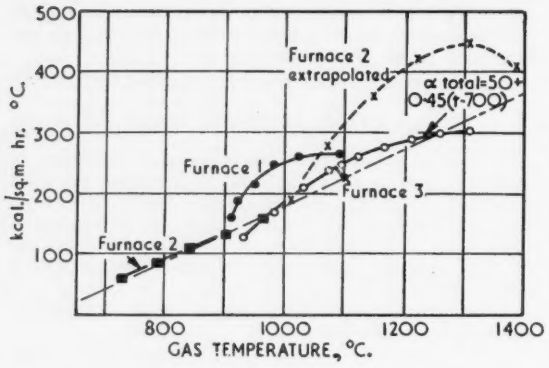


Fig. A—Total heat transfer coefficient as a function of gas temperature (after Schack)

experience suggests that this method predicts a low answer.

Furthermore, I am not convinced that it is useful to calculate a heat-transfer coefficient based on the theoretical flame temperature, as was originally done by Eberhardt and Hottel. This method is insensitive and implies that once a fuel is chosen, heat transfer is independent of the nature of the combustion products and the type of burner. The nearest approximation is with rapid pre-mix burners, where fuel and air may both be supplied under pressure. In the system investigated by Gray and Brooks conditions were far removed from this.

The fact that good agreement is not obtained using the measured temperature at the hot end of the furnace is unfortunate, since it would be convenient to produce a simple equation for the heat transfer in this type of furnace. The disagreement may serve to indicate that the authors are looking for too simple a solution, and that more detailed measurements of the temperature and probably the flow variations of the gases at various positions inside the furnace are required.

Mr. **G. Wellensiek** (Metallurgical Engineers Ltd.): As a member of the company of Dr.-Ing. Schack and Co. in Germany I would like to comment on the heat-transfer figures found by Mr. Gray and Mr. Brooks compared with those which on the formulæ of Schack (1931) and that of Heiligenstaedt (1934) can be calculated.

Schack's formulæ were not based on theoretical reflections but on readings taken at three continuous furnaces, the heating media of which were different kinds of gases. These readings are shown in Fig. *A*.

On the strength of these readings, Schack worked out the following linear formula providing sufficient accuracy for technical calculations with gas temperatures above 700° C.:

$$\alpha_{total} = 50 + 0{\cdot}45\ (t - 700)\ \text{kcal./hr.}\ ^\circ\text{C. sq.m.}$$

where t = true gas temperature (suction pyrometer).

It is pleasant to see these formulæ substantially confirmed by careful readings taken by the present authors, although a certain part is played by the composition of the furnace atmosphere, since heat transfer by means of gas radiation depends on the gas contents of radiating constituents (CO_2 and H_2O).

Discrepancy between the present readings and the earlier results might be due to the definition of the median temperature difference Δt_m, which, as shown in Fig. *B*, is not so obvious at first sight. This definition will certainly be incorrect if it is based on the arithmetic median value, because heat transfer through gas radiation follows the absolute temperature (° K.) on the 3·5 power.

Have the authors also found over a measured section of, say, 2 m. of total furnace length a discrepancy between heat output and heat input of about 20%, the heat input to the steel being larger than heat output from the gas? If so, what is their explanation for this? No explanation could be found for this in the earlier tests, either by temperature readings or by control of the gas composition.

The air loss of 42% in the recuperator is of great importance since it occurs at the hot end. This recuperator was supplied from Germany in 1935, at a time when insufficient experience was available on the reaction of high-chromium steels. Much of the heating surface consists of tubes with a 30% Cr content, which are now known to be liable to embrittlement to a high degree. There are about 600 tubes in the recuperator and the likelihood of air losses is great. Since 1935, however, recuperators have been developed which are better suited for such furnaces.

AUTHORS' REPLIES

Mr. **F. A. Gray** and Mr. **S. H. Brooks**: We should like to thank all those who have contributed to the discussion, and feel particularly grateful to Mr. Southern, who, as a very experienced furnace builder, has so ably commented on our paper. He suggests that a more modern furnace should have been tested, but this one was chosen for reason of convenience and also because the performance of an older furnace was more likely to be improved.

Mr. Southern states that he would rate the optimum capacity of the furnace at 30 tons/hr., but 40 tons/hr. was achieved and always at a lower fuel consumption (billet size being equal) at the higher rates of output. A heat transfer of 28,000 B.Th.U./sq.ft./hr. was also attained, as compared with his design figure of 20,000 B.Th.U./sq.ft./hr. It is admitted, however, that the soaking was not all that could be desired at the higher rates of output, and perhaps Mr. Southern's rather conservative estimates are based on this feature and also on the understandable tendency of equipment manufacturers to "have a little in hand." With two-zone firing an output of 50 tons/hr. might be obtainable.

The top temperature rise of 15° C./min. shown by Fig. 9 was not typical of all the tests and varied with the section being heated. Typical figures, when there were no stoppages, were: 3½ in. thick, 11½° C./min.; 3 in. thick, 14° C./min.; 2½ in. thick, 16° C./min. Two tests (one on 2-in. and one on 2½-in. billets) gave rates

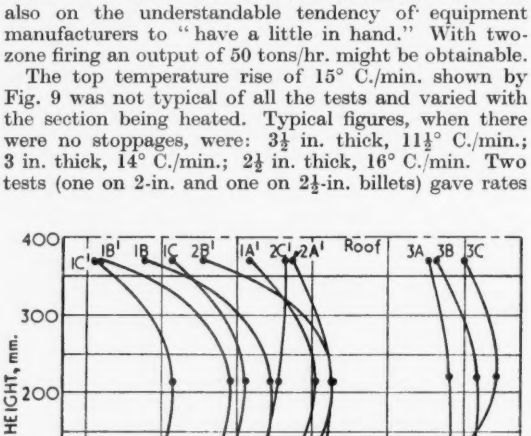


Fig. B—Temperature as a function of height above upper surface of ingot (after Schack)

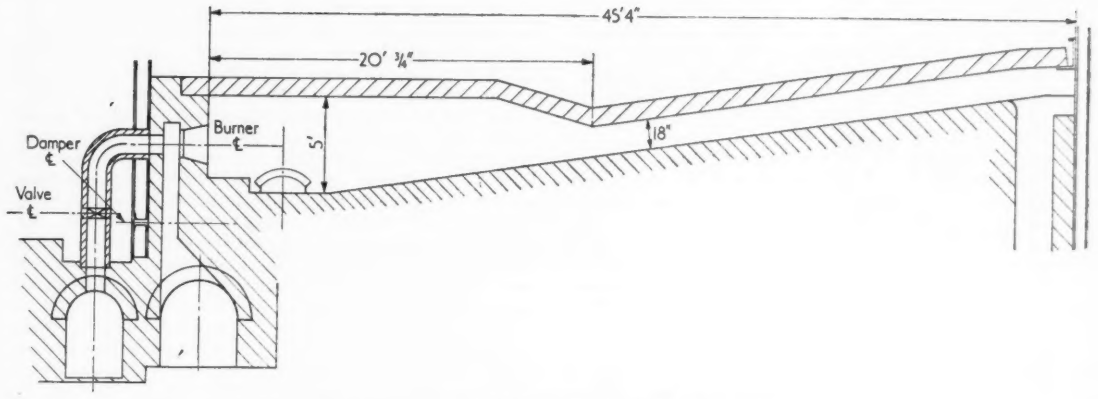


Fig. C—Alterations made to bar-mill furnace

lower than for the 2½-in. billet quoted, but in those cases the mill was controlling the outout of the furnace. The shape of the curve in Fig. 9 is, however, fairly representative of the other tests.

With regard to whether a linear relationship is satisfactory on Fig. 13, it can only be said that there was insufficient departure from a straight line (after correcting the points on the graph for differences in other variables) to justify the use of a curve by statistical techniques.

As pointed out, the furnace pressure was originally set to give the zero-pressure point at the hearth about half-way up the furnace. The tests, however, confirmed that the pressure should have been high enough to give a zero or slightly positive pressure at the discharge door sill. With the furnace as tested it was practically impossible to obtain this condition, even with large quantities of gas being blown out of the charge door. This was due in part to the excessive hearth slope of 1 in 7, but we have since altered the roof contour and installed burners in the front wall directing the flame between stock and roof, as shown in Fig. *C*. With this arrangement it is possible practically to eliminate air infiltration with a centre roof pressure of only about 0·045 in. W.G. with reduced blow-out from the doors in the higher parts of the furnace. Whilst it is agreed that infiltration and blow-out were excessive on the furnace as tested, it is suspected that many modern furnaces suffer in this respect a great deal more severely than their operators imagine.

We are all indebted to Mr. Southern for his explanation of the fundamental relationships in furnace technology; his method of employing the ratio (ϕ) of (heat to steel)/(heat to steel and walls) is particularly neat, but his calculation of the furnace heat balance demonstrates his experience rather than offering a method of calculation. He has assumed an efficiency, and then allocated a value to ϕ, which amounts to assuming a wall loss. The third item of the heat balance is thus obtainable by difference. The good agreement he obtained with the experimental data shows how well he can forecast the factor ϕ. What is really needed is the theory and data to calculate the efficiency, waste-gas temperatures, etc., of given designs of furnace with a particular type of flame.

In reply to Dr. Smith, the wall losses were calculated and were 2·68% as compared with the average difference figure of 4·94%, which tends to support his view that calculation gives a low result. The estimation of blow-out loss, on the other hand, is subject to considerable error, since, although the quantity of lost combustion gas was known, the gas temperature was not known accurately, as the loss is spread out over a considerable area of the furnace. The mean temperature of the furnace gases at the charging end of the furnace was the value used. Thus the discrepancy between wall losses by calculation and by difference could be due to the blow-out loss being on the low side. The agreement is, however, good enough to leave no doubt that the blow-out losses are of the right order.

It is agreed that it seems illogical to base a heat-transfer coefficient on a calculated rather than a measured flame temperature, and the only explanation offered is that although the calculated temperature (taking account of the excess air) would certainly not obtain, it was probably more consistent than the measured ones. Greater accuracy of temperature measurement at the hot end of the furnace would be sought in any future work.

Mr. Wellensiek commented on the fair agreement obtained with the Schack empirical formula for heat-transfer coefficients and suggested that the reason for the discrepancy might be due to using an arithmetic mean gas temperature. This may be so, but Fig. 33 shows that the variation of gas temperature in the furnace height was considerably less than that shown by Fig. *B*, and the errors should not be serious. It is pointed out in the paper that the values for the constant fall between those recommended by Schack and by Heiligenstaedt.

Discrepancies were obtained when attempting to evaluate sectional heat balances; in most zones the heat received by the steel was more than that lost from the gases, but the converse was true at the burner end. The reasons for these discrepancies are delayed combustion, uncertainties regarding gaseous volumes, and velocity patterns and radiation between zones. This was discussed briefly in the paper (p. 260) and Sarjant, Smith, and Bacon* have investigated the problem on a small test furnace. In the paper by Bacon and Sarjant attempts were made to calculate the sectional heat balance of the large furnace described in our paper, but a number of assumptions were necessary. Quite apart from re-radiation, the amount of undeveloped heat must

**J. Inst. Fuel*, 1954, vol. 27, Jan., pp. 16–24; Dec., pp. 582–594.

be known for each section, and even if this is known the calculation of sensible heat of the gases demands a knowledge not only of the air infiltration and blow-out, but also of the velocity pattern in the furnace, so that a properly weighted gas temperature can be obtained. It will be evident that the determination of these latter factors is almost impossible on an industrial furnace.

Professor **R. J. Sarjant**: We could argue on Dr. Brancker's contribution for a couple of hours. Perhaps Dr. Price and Dr. Slack may be allowed to say a few words about that contribution. All the formal mathematical methods were carefully considered by us. The numerical method of integration can be applied to a mechanical machine or an electrical analogy machine. We had the latter, but it was so expensive in condensers and resistances to give the right combination to fit in with the particular conditions of the problem. Furthermore, there was the problem of variable diffusivity, with the changes in temperature which inevitably take place in practice because the rate of heat input is varying. These made desirable the simpler method which we finally adopted.

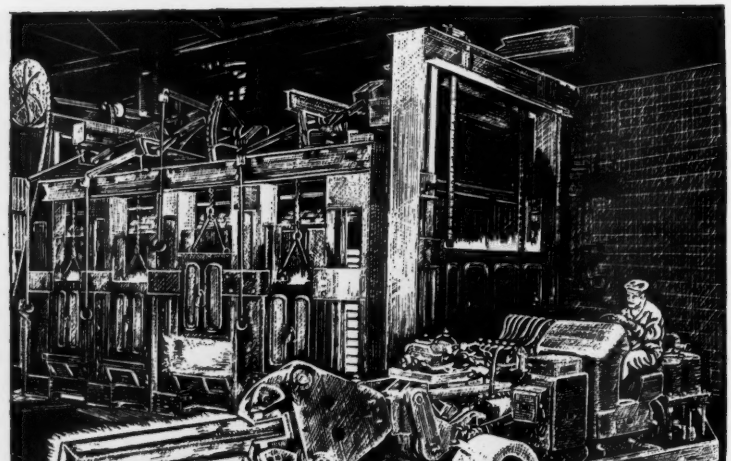
In regard to Dr. Price's remarks about the rate of utilization of heating surface, it is the coefficient with which I am primarily concerned.

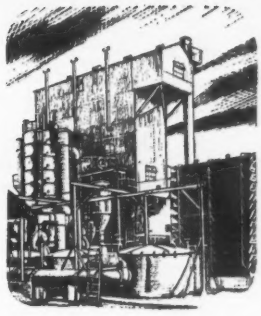
Dr. **P. H. Price**: Both Professor Sarjant and I want to know k, in whichever of B.Th.U./sq. ft. or B.Th.U./ cu. ft. is more useful.

In reply to Dr. Brancker, I should like to deal with the point made about what appears on p. 432, where the distance is suggested as the square root of time. This is only a general discussion of solidification, including the work of other people. We did not assume this; it can be proved from the calculations, and this has been done. This paper and the previous papers which have led up to it fairly carefully make the point clearer. We are quite happy about the theory; it has been before the mathematical world for two years in the *British Journal of Applied Physics*, and appears to be well established. So far as the use of constant thermal properties is concerned, graphs of the solutions, in a form in which engineers can use them, are available, but they are not really relevant, because with these constant thermal properties they are simply not valid. Standard solutions in the case of varying thermal properties will not come for a long time. There are existing a few analytical solutions of the heat-flow equation where thermal diffusivity depends on temperature. These solutions cannot very well be applied to industrial cases. I hope that some day it may be possible to extend them. We have used them as a sort of calibration of the numerical methods, and we find that the numerical methods agree very well, even in these cases of thermal diffusivity depending on temperature. At first sight it appears to be technically possible to do an integration using text-book methods and assuming constant thermal properties over a small time range, and then stop to take other values of thermal properties over the next time range, but when you find that the thermal properties vary not only with time but also with distance through the billet, this becomes almost impossible.

Dr. **M. R. Slack**: I think that Mr. Siddall is making a very noble attempt to find the effects of gap formation. His work provides corroboration of the nature of the formation of a gap between an ingot and its mould. It will be interesting to see if he finds as we did that the effects of gap formation on the temperature distribution die away and are of little consequence at the time the ingot is rolled.

In regard to Dr. Brancker's contribution, I think that the methods which he suggests are, for continuous casting, amongst the best which we can apply, but I do not think that they would be applicable to the case under discussion. If varying thermal quantities and variable heat transfer are introduced, the method would be at best approximate, and just as lengthy as the methods which we have used.





THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE TWENTY-EIGHTH MEETING

The TWENTY-EIGHTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2, on Wednesday, 23rd March, 1955. Mr. W. M. LARKE, Chairman of the Group, was in the Chair.

At the MORNING SESSION, a paper by Capt. (E) W. GREGSON, R.N.R., entitled " Some Comments on Waste-Heat Recovery Practice," was presented and discussed. A report of the morning session appeared in the August, 1955, issue.

At the AFTERNOON SESSION, the paper presented and discussed was " Waste-Heat Recovery Related to the Generation of Electric Power," by Mr. W. ERNEST, A.M.I.Mech.E. (which was published in the March, 1955, issue). A report of the discussion at the afternoon session appears below.

PROCEEDINGS OF THE AFTERNOON SESSION : 2.15 P.M. to 4 P.M.

Discussion on the Paper—

WASTE-HEAT RECOVERY RELATED TO THE GENERATION OF ELECTRIC POWER*

Mr. **W. Ernest** (United Steel Companies Ltd.), in presenting the paper, said that much of what he had suggested had been in the minds of steelplant engineers for many years, and occasionally applied in practice. However, a purpose might be served by assembling the conditions affecting the use of waste heat for the generation of electric power. He had attempted to treat the subject quantitatively but in a general fashion, and the figures of Tables I and II, on which the calculations were based, were related to a hypothetical works of medium size and cold-metal practice. Specific consumption figures were always subject to wide margins, so that he would welcome further information in the discussion.

In Fig. 4 (p. 274) the words at the top should be ' steam production,' not ' steam consumption.'

Dr. **W. S. Walker** (Round Oak Steel Works): The author of this paper, Captain Gregson, and various speakers at the morning session have to some extent spoken self-evident truths. Although the author modestly confessed to little originality, he has defined many aspects of probably the most pressing problem facing the industry, namely, the ever-increasing price of coal, which makes life increasingly tedious for the steelworks engineer. The crux of the paper is the relative costs of coal and electricity. The electric power undertakings are not fair to the heavy industrial user; in other words, we are charged on load factor, and it is a load factor similar to that of the domestic consumer. Even at the

* *J. Iron Steel Inst.*, 1955, vol. 179, pp. 271–279.

risk of its being desperately unpopular, I think there should be a national revision of the electricity charges to the heavy industrial user. If that were done, some of the author's arguments might have to occupy relatively different positions.

On the substance of the paper, I would confirm that the author's figures of consumption, etc., in Table I seem accurate when compared with those of the works with which I am associated. We have no other steam-raising power apart from waste-heat boilers, except two small Lancashire boilers fitted into a ring main for re-starting after shutdown.

My criticisms are negative, because I am in complete agreement with the paper, but there are some comments I must make. I should like to fit steam-cooling on O.H. furnaces. I can see that it can be safely and adequately applied to port-end pipes, but I hesitate to apply it to door jambs. What happens if the charger driver rams the door, and is it possible to fit non-return valves, so as effectively to prevent scalding the operatives ? I have never had a satisfactory answer to these questions. I should also like to know what is to be done about reheating-furnace skids. Can we apply steam-cooling to them, or should we consider all this cooling water as low-grade heat ? Both the author and Captain Gregson might have considered the question of upgrading low-grade heat. Someone should seriously consider developing practical, economic heat-pumps to upgrade the cooling water into a useful form of heat, which might be used for steam raising, using the opposite end of the heat-pump cycle for cooling.

On p. 274 the author says that " Steam production from waste-heat boilers is constant and, to satisfy temporary peak demand without resorting to fuel-fired balancing boilers, capacity installed must be sufficient to cover these peaks." We fitted in our steelworks auxiliary oil-firing in the waste-heat boilers. I believe other works have also done this. We have found that most satisfactory; we can take a furnace off for repairs and still maintain a constant head of steam by auxiliary oil firing. Instead of generating electricity with our surplus steam we use that steam in a steam-turbine and reciprocating pump for pumping cooling water, so that we are doing something similar to the author's suggestion.

The question of reducing peak load in steelworks by a method similar to this should be investigated. I suggest it is time that B.I.S.R.A. made a survey to see just what could be done nationally in the industry.

Mr. **Ernest**: Dr. Walker has quite correctly and courageously reminded us that we pay too little for our electric power as private citizens and too much as industrial engineers.

His achievement in balancing his works steam supply and demand within $\pm$ 2000 lb./hr. is excellent, and confirms the suggestion in the paper that a reasonable continuity of steam and power production seems possible without difficulty.

Dr. Walker's doubts of the mechanical and operational safety of steam-cooled open-hearth furnace parts are echoed by many operators, and will not be resolved until an installation is operating in the U.K. Evidence from the Continent cited in the bibliography indicates its practicability and success after trials lasting several years. Accidental failure of steam elements should not be any more dangerous than failure of the existing cooling-water elements as long as suitable non-return valves are used.

There seems to be no reason why water-cooled reheating-furnace skids should not be similarly converted to steam cooling. The problem seems to be that reheating furnaces are rarely equipped with waste-heat boilers to which a steam-circulating system can be attached.

The problem of the use of heat pumps for space heating has been discussed many times. Even at present fuel prices it is uneconomic.

Mr. **C. E. Sayer** (McLellan and Partners): I should have thought that with the present level of coal prices, and with the load factors associated with steelworks' operations, it could almost be considered certain that it would pay to produce all the waste-heat steam reasonably possible, even though the only use to which some of it could be put would be the generation of electricity. The only condition which might affect that generalization would be where a high proportion of space heating in the steam demand detracts from the otherwise good load factor of utilization of the steam.

I am surprised by the suggestion that the production of steam from door-frames in O.H. furnaces is a sort of waste product, and that the main purposes in using steam cooling are to save cooling water and to make maintenance easier. In some works the saving of water may be of vital importance, but this can be achieved in other ways and I should not have thought that turning the door-frames from plain water-jackets to evaporator elements would necessarily lead to easier maintenance. In addition if the water is to be evaporated in the frames it would have to be treated to a much higher degree than if it is only to be heated a few degrees. Usually the outlet water temperature is not much above 110–120° F. and no doubt it is often given no treatment at all.

I am puzzled by the author's reference to back-pressure turbines in relation to the underlying idea of the paper. Since he devotes his whole attention to the use of waste-heat steam surplus to works demands for the purpose of electrical generation, the only type of turbine which could be used would be a straight condensing machine, taking steam at the pressure which he assumes of 175 lb./sq. in. A pass-out condensing turbine would imply using the steam which is demanded by the factory for electrical generation as well, passing that out and letting the surplus steam proceed to the condenser, which would mean producing all the steam at a higher pressure than the works require.

On the question of boiler pressure, I am not sure if the author is referring mainly to waste-heat boiler capacity added to existing units. If so, the pressure of 175 lb./sq. in. might be dictated by the pressure of the existing boilers, but even with shell boilers (if water-tube or forced-circulation boilers are not liked) on any new installation one would feel that a pressure of 175 lb./sq. in. was far from progressive.

Table I gives the estimated power and steam demands for the author's typical steelworks, and here I would remark on the smallness of the pickling department's steam demand in relation to the others.

In Table II the author gives the output from O.H. furnace waste-heat boilers as 15,000 lb./hr. per unit, taking the 100-ton furnaces, and of this he ascribes 4000 to the cooling frames, an addition of 35%, compared with the 20% mentioned earlier by Captain Gregson and the 50% referred to by Mr. Ungoed.

I am puzzled by Figs. 2 and 3, and I would like an explanation of the expression below the horizontal scale, " Time above load, %."

In the second column on p. 273 the author refers to a load factor of 90%. The 514,000 kWh./week from waste-heat steam I make out to be a 90% load factor on 3400 kW., not 4500 kW. It appears that he is jettisoning his 4500 kW. peak availability of steam, and that is confirmed by his statement that " only on very rare occasions will the base load of the works drop below 3400 kW."

If the maximum availability represents 4500 kW., that is not being used to the extent of 90%, but somewhere nearer 65%.

It is generally considered uneconomic to install plant to suit the extreme peak, but is the author suggesting that the capacity of the plant should only be for the mean? If so, he will not be able to generate power at that mean level, because he will be cutting off all the peaks.

In Table V the author refers to a plant of 4000 kW. installed capacity which may be the size of plant which he would suggest for the peak availability of 4500 kW. In Fig. 6 the output of 3400 kW. corresponds roughly with the home generation of $25–26 \times 10^6$ units annually, and that agrees with the figures on p. 273, $514,000 \times 50$ weeks being about 26,000,000 annually, so that the plant would not be used at 90% load factor.

In Fig. 5—the steam consumption of turbo-alternators—the author says that he takes account of the fact that the plant would not always be working at full load. Consequently I assume that the figures are to be taken as steam consumptions averaged over the range of working load, because they are considerably higher than the full-load figures one would expect even at 175 lb./sq. in.

On p. 275 there is again reference to a 90% load factor, and it is pointed out that the load factor of the purchased supply will grow worse as that of the works-generated supply improves. That is quite general and perfectly true, but in sub-paragraph (*b*), the author says "It is inherently assumed that the works generators carry a proportional part of the maximum demand." I should like him to clarify that, because it seems inconsistent with his preceding statement. What does he mean by 'proportional'? If the works generators carry a part of the total works demand proportional to the units generated, there will not be this varying load factor on the purchased supply compared with the works-generated supply.

From Table V I deduce that the savings shown by Fig. 7 include an allowance of 5% for depreciation, which is important. Although 5% for depreciation is lower than the figure which most industrialists adopt, it is quite a useful step towards it, and therefore the savings in Fig. 7 do partly cover capital charges, and the figures in Table VI will also include this depreciation allowance.

I have one brief comment on the first paragraph in the second column on p. 277. It is a fact that for some reason Continental firms apparently prefer to sell their blast-furnace gas to a central generating station; they use constant-speed blast-furnace blowers, which are motor-driven, and then buy the power back. I do not know why, but from visits to a number of plants it seems a very common practice on the Continent.

On p. 278, the author suggests that there is no evidence yet of the practicability of gas turbines working in conjunction with hot waste gases. In my opinion that is too guarded. I would have said that there was little doubt about the fundamental practicability. Operating difficulties are another matter, although I think that in general they can be solved.

On the same page the author deals with electrical plant, and, referring to synchronous generators, he says, "If the generator is of appreciable capacity in comparison with the total network capacity some automatic voltage regulation may be required." In the U.K. it can be assumed that any private plant running in parallel with an outside supply will be in parallel with the Grid, so that this problem does not occur. Nevertheless, an automatic voltage regulator should be provided, because there is always the possibility that the set or sets may have to run temporarily disconnected from the Grid. There is also another use for the automatic voltage regulator on plant actually running in parallel with the Grid, and that is to maintain the excitation constant at any desired value (up to the maximum-rated excitation), by means of which the maximum power-factor correction is obtained from the local generators at all times, whatever those generators may be producing in kilowatts. This application is perhaps new, but it has proved in practice to be very successful.

On the subject of asynchronous generators, the author refers to their main limitation, namely, that the failure of the external supply would also cause the supply from the works generator to fail, so that any standby value of the plant is lost. On the other hand complete reliance for standby supply could not be placed in any case on a generator working solely on waste-heat steam if there is no auxiliary fuel available.

I was once concerned with planning one of the earliest cases of running an asynchronous alternator driven by a back-pressure turbine, and I took advantage of the fact that this particular works fortuitously had a double-busbar switchboard to put a synchronous alternator in tandem with the asynchronous generator, the synchronous alternator running excited on the reserve set of bars so that it was all the time ready to take the load if the outside supply failed. That was one way of overcoming this limitation.

A warning is needed against excessive power-factor correction of asynchronous generators. If one goes too far towards bringing them up to unity power-factor, one is on the way to falling into resonance, and the moment the asynchronous alternator and its capacitor have been energized from the supply, even for two or three cycles, if they are then disconnected from the supply the voltage will swing away, and nobody knows quite how far it will go. Concerning the simplicity of operation of the asynchronous generator, I do not think too much should be made of the avoidance of synchronizing. This requirement of the synchronous alternator normally presents no difficulty, and to avoid heavy switching currents the asynchronous machine has to be run up to near synchronous speed before it is switched in.

Mr. **Ernest**: Mr. Sayer has mentioned many points which for reasons of space and clarity have been left incomplete in the text of the paper. It is not necessarily true that waste-heat steam production must always be economical since the marginal quantities available for power production must always be small and variable, which does not make for generating efficiency.

I cannot agree that equivalent cooling-water economy can be attained by other methods than steam cooling, because the amount of water used is equivalent to that of the steam produced; this would naturally have to be treated to boiler-water standards. However, for a 100-ton open-hearth furnace the water requirement is only 300–600 gal./hr. compared with 15,000–30,000 gal./hr. when water cooling is practised. Although the use of cooling ponds or towers will cut make-up to a minimum, 5% or 1000 gal./hr. is still lost.

Alternatively, the whole of the water can be drawn from an available source and rejected without recirculation. The choice is between the use of a large amount of water incurring pumping and filtering costs, and capital investment in cooling towers with similar pumping costs. Either of these costs certainly exceeds the additional treatment cost for a small amount.

It is true that the use of pass-out turbines would involve the whole of the steam produced and implies an accurate balance between power and process steam demands. This would be in line with Mr. Sayer's further point regarding increased boiler pressure. The reason for the choice of the comparatively low pressure of

175 lb./sq. in. was recognition of the fact that normally additional capacity would be added to already existing plant working at such pressures.

The steam allocation for pickling is in line with normal practice, and reference to Table I will show that only about 1000 tons/week of hot-rolled strip are produced in the works. The figure of 4000 lb. produced by the door-cooling frames of a typical open-hearth furnace is based on design figures submitted by the manufacturers, and it happens that this falls exactly half-way between the percentages of 20 and 50 mentioned in the discussion on Captain Gregson's paper. Actual production from cooling elements will depend on the size of the furnace and on its state of repair, and the assumed figure appears to be a reasonable compromise. Figures 2 and 3 are intended to demonstrate the percentage of time during which a certain steam or power load is exceeded. They are derived from a plot of the frequency distribution and load variation was expressed in this way because these curves are of similar shape for works of widely different power demands and production capacities.

Mr. Sayer has rightly pointed out inconsistency in the use of the term 'load factor.' In the context of the paper the 90% load factor is taken on the steam availability and not on the installed generator capacity, which is the more normal denominator when dealing with fuel-fired boilers. The optimum size of generator to be installed in any particular application depends upon the shape of Fig. 3, and it will obviously pay to jettison a few hundred kW. peak availability of steam occurring for a very short time. An installed capacity of 4000 kW. is suggested in this case, which represents a reduction of the utilization factor by 11% during about 10% of the time.

The statement on p. 275 referring to a " proportional part of the maximum demand " is used in the sense that the amount of maximum demand carried by the works supply is proportional to the number of units generated.

Depreciation of 5% has been included both in Table VI and in Fig. 7, but Fig. 7 is unrepresentative since it takes no account of the reduction in the cost of steam not passing through the generating system. A 5% depreciation allowance is, of course, not enough to justify the adoption of home generation and is only intended as part of the operating costs.

The Continental practice referred to is an interesting example of an attempt to improve the diversity factor of blast-furnace gas availability and power demand. This may be one method of overcoming diversity problems arising from the increase in the size of blast-furnaces with a corresponding reduction in number, but attendant problems of allocation should not be overlooked.

Mr. Sayer has made several valid points on the electrical problems inherent in parallel operation which I am not competent to discuss.

Mr. **J. H. Flux** (United Steel Companies Ltd.): I should like to say something on the question of steam cooling or, as it should be called, 'hot cooling.' Three excellent papers were published in *Stahl und Eisen* in July, 1953,* describing the installations made in Germany. Compared with normal cooling the following advantages are claimed for hot cooling:

(i) Substantial savings in water consumption
(ii) Prolonged life of the cooling elements
(iii) Utilization of the heat carried away from the furnace by the cooling medium,

and based on a personal investigation, last year, of the German installation I would say that these claims are largely justified. As a result of this, we are now negotiating for an initial trial installation on a 100-ton cold-metal furnace.

I wish to refer to Dr. Walker's question concerning the safety of installing a pressure vessel on a steelmaking furnace, and I would suggest that the danger is no greater than with the traditional type of water cooling. Seven different installations were inspected, but no frames had failed during service, even though the door frames had been struck by the charging machines, and the operators were no longer worried about this possible source of personal injury. To withstand the higher pressures involved, the door frames are fabricated more substantially and to minimize any possible danger are constructed in three sections instead of in the **H** design used in normal water cooling. Non-return valves are fitted, so that if a fracture occurs, the quantity of cooling fluid released would be much less than with water cooling.

The saving through reduced water consumption is considerable, assuming that the steam generated is usefully employed so that the load on other boiler plant can be reduced. Water treatment is important, but as a correspondingly smaller quantity of boiler feed water has to be treated, I cannot agree with Mr. Sayer that it is expensive. The water treatment, especially de-aeration, plays an important part in prolonging the life of the cooling element and for this alone the cost of water treatment might be justified. Whereas with normal water cooling the life of the frame is indefinitely short, the forced circulation of large quantities of treated water, as in hot cooling, makes for longevity and in Germany door frames are still in use after operating for two years.

The savings through using the heat carried away by the cooling medium are fantastic and have not been seriously disputed; but I think that the method, used in the discussion today, of expressing this as a percentage of the waste-heat boiler capacity is wrong. The door frames used in Germany generate approximately 1500 lb. of steam per hour per frame, and this is additional to the quantity generated by the waste heat boiler which remains constant. The quantity generated by the door frame was almost the same for 60- and 120-ton furnaces, a bigger variation being noted as a result of the deterioration of the furnace lining as the campaign progressed rather than by the change in furnace size.

These results appear to apply equally well to the two systems in use in Germany. One system operates at 0·5 atm., and is designed to avoid the need for a boiler (plus insurance etc.), but this arrangement generates low-pressure steam which can be used only for space heating and hot water purposes. The other system works in conjunction with the waste-heat boiler generating steam at boiler pressure with obvious advantages. Installations already working vary between 12 atm. (180 lb./sq. in.) and 45 atm. (650 lb./sq. in.) and designs are available for operation up to approximately 95 atm. The trial installation, to which I referred earlier, is of this latter system and should operate at a boiler pressure of 180 lb./sq. in.

Mr. **R. Dingwall** (Dorman Long (Steel) Ltd.): The use of economizers with waste-heat boilers does not result in the optimum thermal efficiency.

When steam is used in a condensing turbine, of the heat put into it at the boiler about 75% is rejected to the circulating water. There is a comparable loss of heat up the boiler stack. In central power-station practice they reduce both of these heat losses. The condenser loss is reduced by the bleeding of steam from the turbine to give the maximum feed-water heating, such steam

* H. Lardy, *Stahl u. Eisen*, 1953, vol. 73, pp. 1028–1030; A. Harnisch, *Ibid.*, pp. 1026–1028; K. E. Poppe, *Ibid.*, pp. 1030–1035.

following a theoretical cycle efficiency of 100% instead of about 25% via the condenser. This precludes the use of economizers; but the chimney-stack loss is reduced by the use of the heat exchanger, which transfers heat from the stack gases to the combustion air. I suggest that it is economic in a steelworks to have a low-pressure steam system fed from a pass-out turbine, the steam to be used for oil heating, space heating of offices and maintenance shops, heating of water for offices and welfare buildings, etc. This low-pressure steam could be used also for feed-water heating. Heat exchangers are then required to transfer heat from the stack gases to the air going into the checkers.

I am apprehensive of the proposed application of steam cooling on steel furnaces. The simplest system of water cooling is the open system where one end of each cooler is connected through a valve to a common supply pipe and the outgoing water runs into a tundish. This has the merit that the cooler is permanently open to atmosphere at one end. The next stage is the closed system, which has an obvious advantage for tilting furnaces, but since there are headers on the supply and return side of the coolers, two valves per cooler are necessary for isolation. This means that it is possible to have a cooler isolated at both ends, and so a relief valve becomes necessary. The proposed operation of the coolers under pressure is a further stage, and considering the precautions that are usually taken with boilers and pressure vessels, I wonder if a sufficiently high standard of maintenance and testing would be practicable for furnace coolers.

Mr. **Ernest**: Mr. Dingwall is right in suggesting feed heating as a more efficient thermal cycle than economizers. However, with waste-heat boilers we must remember that it is the boiler and steam turbine which is auxiliary to the open-hearth furnace which, from the power-plant engineer's point of view, is only a combustion chamber. It has been shown that preheating the air to a limited degree does not reduce the volume of regenerators to any extent, although there would be some benefit in terms of steam production because of the higher waste-gas temperature entering the boiler. Such a scheme is suggested in connection with gas-turbine applications in Fig. 9*a* of the paper.

The use of a separate low-pressure steam system for process heating is desirable but duplicates the amount of maintenance and sources of leakage and loss. On the whole, steam mains are not as efficient as they might be in the average steelworks, and for existing plant it is doubtful if the capital cost of separate low-pressure steam supply can be warranted where a mains system already exists.

The question on maintenance of steam-cooled open-hearth furnace parts has already been referred to in answering Dr. Walker and by Mr. Flux.

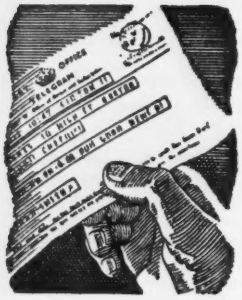
Captain **W. Gregson**: As long as we ignore the orthodox water-cooling technique and design the steam-cooling arrangements on water-tube boiler principles, I am sure the insurance companies and the Factory Inspectorate will be satisfied. Good water, properly treated, will be used as in normal waste-heat boiler practice.

Mr. **E. M. Noyes** (Hartons Installations Ltd.): I am away from the industry at the moment, but I am surprised to find that the emphasis still seems to be placed on low–medium pressure shell-type boilers. Until a few years ago the bulk of steam was used for machine drives, reversing mill engines, hammers, etc., or for processes where comparatively low pressures are required. We are now entering the era of the integrated works, electrically driven from the public supply or supplemented by its own power house. There appears to be a good case for raising steam from waste heat at, if possible, main power-house pressure, and feeding it back to the central station. This would avoid the throng of small prime movers which would arise from gas turbines, each requiring a driver. The function of a gas turbine or waste-heat boiler is merely to convert waste energy from the untidy form of a hot dirty gas into a useful form such as steam or electricity.

Mr. **W. Ernest**: The use of steam at normal power-station pressures has already been referred to several times in the discussion and I can only repeat that most of the suggestions of the paper referred to existing works and more particularly to cold metal shops.

Large integrated steelworks have in many cases power stations comparable in size and efficiency with main B.E.A. stations, but there the production of power is based on the use of surplus by-product gases.

It hardly seems feasible to consider high-pressure steam generation with the attendant treatment and other difficulties in a works producing power from waste-heat steam which at best can give up to 10,000 kW. You must have more than one generating unit and it is doubtful if the advantages of high pressure/temperature steam can repay its cost in units of 4–6 MW. Even if waste-heat power is supplemented by fuel-fired boilers, unit size would still be small, and such a combination could hardly be expected to cost less than the public supply.



N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Special Meeting in Scunthorpe, 1955

As previously announced, the Council of The Iron and Steel Institute have accepted an invitation from the Lincolnshire Iron and Steel Institute to hold a Special Meeting in Scunthorpe, from **Wednesday, 12th October, to Friday, 14th October, 1955.** A Reception Committee has been formed in Scunthorpe under the Chairmanship of Lieut.-Comdr. G. W. Wells, R.N.(Ret.), D.L., President of the Lincolnshire Iron and Steel Institute; a Ladies' Committee has also been formed, and Mrs. G. W. Wells has kindly consented to act as Chairman.

The following is the programme:

Tuesday, 11th October

Members and Ladies arrive in the Scunthorpe area.

Wednesday, 12th October

Morning: Opening Session at the Drill Hall, Beck Road, Scunthorpe, followed by the presentation and discussion of the following papers:

"*Developments in Ironmaking at Appleby-Frodingham*," by G. D. Elliot

"*The Expansion Scheme at John Lysaght's Scunthorpe Works Ltd.*," by W. L. James.

Afternoon: Visits to works and ore mines with lunch and tea by invitation of the Companies visited (*see* below).

An all-day visit to Lincoln with lunch and tea will be arranged for the Ladies.

Evening: Reception and Buffet Supper at the Baths Hall, Scunthorpe, by invitation of the Mayor and Corporation of Scunthorpe.

Thursday, 13th October

Morning: There will be two simultaneous technical sessions for the presentation and discussion of the following papers:

(Session *A*—in the St. Lawrence Church Hall, Scunthorpe)

"*Steelmaking at Redbourn*," by S. R. Isaac

"*Organization for Maintenance*," by J. L. Gaskell.

(Session *B*—In the Lecture Theatre, North Lindsey Technical College, Scunthorpe)

"*Underground Mining of the Frodingham Ironstone Bed at the Dragonby Mine, Scunthorpe*," by C. Smith

"*Development of Chemical Methods for the Treatment of Low-Grade Ores at Appleby-Frodingham*," by L. Reeve.

Afternoon: Visits to works and ore mines with lunch and tea by invitation of the Companies visited (*see* below).

Ladies will visit the Old Hall, Gainsborough, for lunch, and Normanby Hall (by kind permission of Lt.-Col. E. C. R. Sheffield, D.L., J.P.) for tea.

Evening: Dinner and Dance by invitation of the Lincolnshire Iron and Steel Institute at Elsham Hall (by kind permission of Capt. J. Elwes).

Friday, 14th October

Morning (Members and Ladies): Visits to works and ore mines (*see* below).

Technical Sessions

The papers to be presented at the Technical Sessions on Wednesday and Thursday, 12th and 13th October, were published in the September issue of the *Journal*, with the exception of that by C. Smith, which is published in this issue, pp. 150–158.

Visits to Works and Ore Mines

The following works visits will be available to Members on the afternoons of Wednesday, 12th, and Thursday, 13th October, and to Members and Ladies on the morning of Friday, 14th October:

(i) Appleby-Frodingham Steel Co. ('Seraphim,' blast-furnaces, sinter plant, ore-preparation plant)

(ii) Appleby-Frodingham Steel Co. (open-hearth steelplants, plate mills, section mills)

(iii) John Lysaght's Scunthorpe Works Ltd. (blast-furnaces, open-hearth steelplant, rolling mills for billets, rods, and sheet bar)

(iv) Richard Thomas and Baldwins Ltd., Redbourn Works (blast-furnaces, open-hearth steelplant, rolling mills for billet and sheet bar)

(v) Thos. Firth and John Brown Ltd. (steel foundry)

(vi) The United Steel Companies, Ltd., Dragonby Ironstone Mine.

Eighth Hatfield Memorial Lecture

At the invitation of the Council of the University of Sheffield, Dr. E. C. Bain, Vice-President, Research and Technology, United States Steel Corporation, has agreed to deliver the Eighth Hatfield Memorial Lecture.

The subject of the Lecture will be "*Trends in Metallurgical Research in the United States*," and it will be given at 6.30 P.M. on **Monday, 17th October, 1955,** in the Firth Hall of Sheffield University.

The Council of the University extends a cordial invitation to all members of The Iron and Steel Institute to attend the Lecture. Admission will be by ticket only, and applications should be made to the Registrar, The University, Sheffield 10, without delay.

Autumn General Meeting, 1955

The **Autumn General Meeting** of The Iron and Steel Institute will be held on **Wednesday and Thursday, 16th and 17th November, 1955.** The programme will include the presentation and discussion of papers on Low- and High-Sulphur Oils for O.H. Steelmaking, by C. A. Edwards; Thermodynamics of Carbon Dissolved in Iron

Alloys, by E. T. Turkdogan and others; Solubility of Nitrogen in Iron, by J. D. Fast and M. B. Verrijp, and by E. T. Turkdogan and others; the Strain Ageing of Iron, by B. Jones and R. A. Owen-Barnett, and by W. R. Thomas and G. M. Leak; Examination of Iron Samples Containing Inclusions, by F. B. Pickering and R. E. Lismer; Metallography of Delta-Ferrite, by K. Kuo. In addition, on the first day, a film on the operation of the B.I.S.R.A. Furnace Scanning Periscope will be shown in conjunction with the presentation of a paper on the subject by C. Burns. Full details of the programme will be given in the November issue of the *Journal*.

NEWS OF MEMBERS

▶ Mr. R. J. BROWN of the Nuffield Central Research Laboratories has been appointed Materials Engineer for the British Motor Corporation.

▶ Mr. ARTHUR DONALD BUSBY, A.I.M., has resigned from The Mond Nickel Co., Ltd., and has taken up the post of Deputy Process Development Manager of the Titanium Department of I.C.I. Ltd., as from September 1st, 1955.

▶ Mr. LEWIS CHAPMAN, C.B.E., has been appointed Chairman of William Jessop and Sons, Ltd., and J. J. Saville and Co., Ltd.

▶ Dr. S. F. DOREY, C.B.E., Chief Engineer Surveyor of Lloyd's Register of Shipping, has been re-elected a Vice-President of the British Internal Combustion Engine Research Association.

▶ Dr. JOHN F. ELLIOTT has been appointed Associate Professor of the Massachusetts Institute of Technology.

▶ The Rt. Hon. the VISCOUNT FALMOUTH has been re-elected President of the British Internal Combustion Engine Research Association.

▶ Sir CHARLES BRUCE GARDNER, President of The Iron and Steel Institute, has been made an Honorary Member of the Chemical, Metallurgical, and Mining Society of South Africa.

▶ Dr. M. K. PATWARDHAN has been appointed a Senior Scientific Officer (metallurgist) with the Indian Naval Chemical and Metallurgical Laboratory, Bombay.

▶ Mr. W. S. TURPIN has resigned from Messrs. Hepworth and Grandage Ltd., and has taken up an appointment as Company Metallurgist with the British Tabulating Machine Co., Ltd.

▶ Mr. F. WARDROBE is resigning from the Board of Directors of William Jessop and Sons Ltd., but will be available as Engineering Consultant.

▶ Mr. E. R. S. WATKIN has been appointed General Manager to the Yorkshire Engine Co., Ltd., part of the United Steel Companies organization, as from September 1st, 1955.

▶ Mr. A. N. WHITING has been appointed Steel Specialist with African Oxygen and Acetylene (Pty.) Ltd.

▶ Mr. J. G. WISTREICH has been appointed Deputy Head of the Mechanical Working Division of the British Iron and Steel Research Association.

Obituary

Mr. WALTER KERSHAW of Bolton, Lancs.

IRON AND STEEL ENGINEERS GROUP

A half-day meeting of the Engineers Group will be held at the Engineers' Club, Manchester, on the morning of **Thursday, 20th October,** in connection with the National Fuel Efficiency Exhibition. Mr. J. F. R. Jones, of John Summers and Sons Ltd., will be in the chair, and Dr. W. S. Walker, of the Round Oak Steel Works Ltd., will present a paper on "*Fuel Efficiency in the Iron and Steel Industry.*"

AFFILIATED LOCAL SOCIETIES

Swansea and District Metallurgical Society

The Swansea and District Metallurgical Society is arranging to hold a Joint Meeting with The Iron and Steel Institute on Wednesday, 23rd November, 1955, at which Mr. M. D. J. Brisby will lecture on delays in the supply of scrap to open-hearth furnaces due to furnace bunching. The meeting will be held in the Central Library, Swansea, and will commence at 7.0 P.M.

NEWS OF SCIENCE AND INDUSTRY

Corrosion Symposium—London

The Corrosion Group of the Society of Chemical Industry has arranged to hold a Symposium on the Protection of Cable Sheathing on Friday, 18th October, 1955. The meeting will be held at the Institution of Electrical Engineers, Savoy Place, London, W.C.2.

Further details and forms of registration may be obtained from the Secretary at 56 Victoria Street, London, S.W.1.

Automation

The Institution of Chemical Engineers and the Society of Instrument Technology are organizing a Joint Conference on Automatic Control in the Process Industries. It will be held at Caxton Hall, Westminster, London, S.W.1, on Tuesday, 4th October, 1955.

The Conference is intended to benefit those without specialized knowledge of automatic controls, and to help in the clarification of terminology, definitions, and scope.

Further particulars may be obtained from the General Secretary, The Institution of Chemical Engineers, 56 Victoria Street, London, S.W.1.

Lectures on Metallurgy

Four lectures are to be given, from 20th to 25th October, 1955, by Dr. R. F. Mehl of the Carnegie Institute of Technology. The meetings will be held in the Metallurgical Lecture Theatre of the Royal School of Mines, South Kensington. The subjects of the lectures will be: Thursday, 20th October—"*Diffusion*"; Friday, 21st October—"*Vapour Deposition*"; Monday, 24th October —"*The Pearlite Reaction*"; and Tuesday, 25th October —"*Ferrite, Bainite, and Cementite in Steels.*"

Institut für Härterei-Technik

The German Institute for Hardening Technique has arranged to hold an International Discussion on Gas-Carburizing at Stuttgart on 20th October, 1955. Admission will be by invitation only. Those interested in taking part in the meeting are invited to request further information from the Institute at Postfach 13, Bremen-St. Magnus, Germany.

Colloquium on Hardening—Essen

The Institut für Härterei-Technik is holding the eleventh "Harterei-Kolloquium" in Essen from 13th to 14th October, and in Munich from 18th to 19th October, 1955. Those wishing to take part are invited to write to Arbeitsgemeinschaft Härterei-Technik, Geschäftsstelle, Postfach 13, Bremen-St. Magnus, Germany.

Production and Application of Alloy Steels

A Symposium on the Production, Properties, and Applications of Alloy and Special Steels is to be held in Jamshedpur, India, from 1st to 3rd February, 1956. It is being organized by the National Metallurgical Laboratory of Jamshedpur.

Industrial Applications of Atomic Energy

The Union Carbide and Carbon Corporation have announced the formation of a new Division—Union Carbide Nuclear Company—to integrate the Corporation's diverse activities in the field of atomic energy. It is intended that large-scale research and development activities will be carried on by the new Company.

Visits to Elecfurn Works

During extensive building operations at the Elecfurn works of Wild-Barfield Electric Furnaces Ltd., the company are unable to provide facilities for organized visits as in previous years.

Iron Production at Ebbw Vale

A 50% increase in the weekly output of iron at the Ebbw Vale works of Richard Thomas and Baldwins Ltd. has been made possible by the recent introduction of simultaneous working of three blast-furnaces instead of two. The new furnace has a hearth diameter of 18 ft. and is capable of a weekly output of 3400 tons of iron.

Additional coke ovens have been installed and a new quarry has been opened up to meet the increased demands for coke and limestone.

High-Temperature Refractory

A concrete made up of Secar 250 and corundum aggregate can be used for withstanding service temperatures of up to 1800° C. This calcium–aluminate refractory cement is now being marketed by the Lafarge Aluminous Cement Co., Ltd.

Standard Samples of Basic Slag

A series of basic slag samples, specially standardized for sulphur by the method described in B.S.1121: Part 29: 1953 (*see also* J.I.S.I., 1954, vol. 17, p. 233), is now available from the Bureau of Analysed Samples, Ltd., Newham Hall, Middlesbrough.

The samples have been prepared for obtaining the empirical factor necessary when determining sulphur in basic slags by the rapid combustion process, in connection with slag control in the basic O.H. process.

B.S.C.R.A. Annual Report

The second Annual Report of the B.S.C.R.A., published recently, contains details of developments in the organization of the Association (including the acquisition of a site for proposed new laboratories), and of research carried out during the year. Appendixes list the future programme of research, members, council, committees, and staff of the B.S.C.R.A., and reports and other publications of the Association.

Carbon Tubing for Corrosive Liquids

A new type of patented tubing, known as 'Metica,' is claimed to overcome the difficulty of fragility when using carbon tubes for the conveyance of corrosive liquids. It is, in effect, two tubes; an inner tube of carbon or graphite is protected by an outer tube of metal, a combination which gives both resistance and high mechanical strength. This tubing is now commercially available together with special fittings that ensure continuity of carbon in the pipe. It is manufactured by the Talbot Stead Tube Co., Ltd., Walsall.

B.I.S.R.A. Operational Research Section

Mr. H. Collcutt, at present Head of the engineering side of the Air Ministry's Operational Research Group, has been appointed Head of the Operational Research Section of B.I.S.R.A., in place of Mr. R. T. Eddison, who has left to take up an appointment with N.A.A.F.I.

DIARY

5th–6th Oct.—British Iron and Steel Research Association—Conference on Steel Works Electric Overhead Travelling Cranes—Harrogate.

11th Oct.—East Midlands Metallurgical Society—Presidential Address, "*The Development of the Research Department of British Railways*," by E. D. Knights—Technical College, Nottingham, 7.30 p.m.

12th–14th Oct.—The Iron and Steel Institute—Special Meeting in Scunthorpe.

13th Oct.—Liverpool Metallurgical Society—Presidential Address by A. E. Griffen—The Temple, Dale St., Liverpool, 7.0 p.m.

17th Oct.—The Iron and Steel Institute—Eighth Hatfield Memorial Lecture: "*Trends in Metallurgical Research in the United States*," by Dr. E. C. Bain—Firth Hall, University of Sheffield, 6.30 p.m.

19th Oct.—North Wales Metallurgical Society—"*Trends in Steelmaking*," by J. Pearson—County Primary School, Plymouth Street, Shotton, Nr. Chester, 7.15 p.m.

20th Oct.—Iron and Steel Engineers Group—"*Fuel Efficiency in the Iron and Steel Industry*," by W. S. Walker—Engineers' Club, Manchester.

22nd–31st Oct.—Société de Chimie Industrielle—28th International Congress on Industrial Chemistry—Madrid, Spain.

24th–29th Oct.—Société Française de Métallurgie—Journées d'Automne—Paris.

25th–27th Oct.—Institution of Mechanical Engineers—Conference on Combustion—Institution of Civil Engineers, Great George Street, London, S.W.1.

1st Nov.—Newport and District Metallurgical Society—"*Iron and Steelmaking at Appleby-Frodingham*," by A. Jackson—Whitehead Institute, Cardiff Road, Newport, 7.0 p.m.

2nd–4th Nov.—Institute of Welding—Autumn Meeting on Inert-Gas Shielded-Arc Welding Processes—London.

3rd Nov.—Leeds Metallurgical Society—"*Grain Boundaries*," by D. McLean—Large Chemistry Lecture Theatre, University of Leeds, 7.15 p.m.

7th Nov.—East Midlands Metallurgical Society—"*Boron in Steel*," by F. B. Pickering—Technical College, Nottingham, 7.30 p.m.

Change of Address

Metal Industries Ltd., Universal House, 60 Buckingham Palace Road, London, S.W.1, now have the following telephone numbers: Sloane 7192–4, 5814, and 5618.

TRANSLATION SERVICE

(The previous announcement was made in the September, 1955, issue of the Journal, p. 89.)

Translation Available

No. 506 (German). G. Boos and J. Willems: "Temperature Measurements in the Open-Hearth Steel Plant." (*Stahl und Eisen*, 1955, vol. 75, July 14, pp. 900–905: discussion, pp. 905–906.)

Charges for Copies of Translations—The charge for translations is £1 for the first copy and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

CONTENTS

	PAGE
Mineral Resources	173
Ores—Mining and Treatment	173
Fuel—Preparation, Properties, and Uses	173
Temperature Measurement and Control	173
Refractory Materials	174
Blast-Furnace Practice and Production of Pig Iron	174
Treatment and Uses of Slags	174
Direct Processes	174
Production of Steel	174
Production of Ferro-Alloys	176
Foundry Practice	176
Heating Furnaces and Soaking Pits	179
Heat-Treatment and Heat-Treatment Furnaces	179
Forging, Stamping, Drawing, and Pressing	180
Rolling-Mill Practice	180
Machinery for Iron and Steel Plant	181
Lubrication	182
Welding and Flame-Cutting	182
Machining and Machinability	182
Cleaning and Pickling	183
Protective Coatings	184
Powder Metallurgy	185
Properties and Tests	185
Metallography	191
Corrosion	192
Miscellaneous	192
New Publications	192

MINERAL RESOURCES

The Wolframite Deposits of Spain. F. Ahlfeld. (*Z. Erz. u. Met.*, 1954, **7**, July, 290–295). This is a survey of 25 deposits of tungsten–tin ore, giving geographical location, geology, mineral content, mining methods, and some production data for the more important localities.—E. C.

Notes on the Iron Ore Series of West Keonjhar and a Part of Bonai, Orissa. B. B. Engineer. (*Tisco*, 1954, **1**, July, 97–102). The physiography, geology, and stratigraphy of the iron-ore series of West Keonjhar and part of Bonai are described and the genesis of banded hematite–jasper is discussed.

A Study of the Thermal Stability of Materials Used in Sintering Machine Pallets. J. B. Caine. (*Blast Furn. Steel Plant*, 1955, **43**, Mar., 315–319). Tests were carried out on grey iron, low-silicon iron, high-silicon nodular iron, and low-carbon and low-alloy cast steel under conditions simulating those of pallets of sinter machines to measure the scaling resistance and dimensional stability.—B. G. B.

ORES—MINING AND TREATMENT

Underground Mining of the Frodingham Ironstone Bed at the Dragonby Mine, Scunthorpe. C. Smith. (*J. Iron Steel Inst.*, 1955, **181**, Oct., 150–158). [This issue].

FUEL—PREPARATION, PROPERTIES, AND USES

Some Fundamental Constants of Chemical Thermodynamics Concerning Combustion and Gasification. J. François. (*Chaleur et Ind.*, 1955, **36**, Feb., 54–56). Heats of formation, heats of reaction, and equilibrium constants are given for a number of compounds and reactions.—T. E. D.

Coke and By-Products in 1953. I. E. Madsen. (*Iron Steel Eng.*, 1955, **31**, Dec., 87–95). The author summarizes the Bureau of Mines Statistics on coke-production; number and capacity of ovens; coke usage, distribution and consumption; and production of natural gas.—M. D. J. B.

The Reconstruction of the Coke-Oven Plants in the German Federal Republic. K. Sassenhof. (*Glückauf*, 1955, **91**, Jan. 29, 139–144). The reconstruction of plants destroyed or damaged during the war years in Western Germany is described.

Determination of the Permeability of Coke-Oven Walls. Z. Medřický. (*Paliva*, 1955, **35**, (2), 41–46; (3), 67–73). [In Czech]. The sources of gas losses are analysed for various designs of coke ovens, and methods for the reduction of losses are indicated.—P. F.

The Influence of Operating Conditions of Coking Ovens on the Yield of Chemical By-Products. A. Kozina. (*Hutnické Listy*, 1955, **10**, (1), 10–15). [In Czech]. Experimental results on the optimum operating conditions for coke ovens are given and discussed. The general use of double receptacles, leading from the collector space above the charge, is recommended as affording a better control of the operation. The use of a single receptacle is less efficient.—P. F.

TEMPERATURE MEASUREMENT AND CONTROL

The Design of Suction Pyrometers. T. Land and R. Barber. (*Trans. Soc. Instrument Techn.*, 1954, **6**, Sept., 112–130). A mathematical theory of suction pyrometers is given in the appendices to this article, from which data bearing on the design of the pyrometer for a particular application can be obtained. Two methods are given for the calculation of the efficiency of the pyrometer. In the first the ratio $\frac{T_{max.}-T_0}{T_{max.}-T_{\frac{1}{4}}}$ is used, where $T_{max.}$ is the temperature with maximum gas velocity, T_0 and the $T_{\frac{1}{4}}$ indicated temperatures at zero gas velocity and $\frac{1}{4}$ of the maximum, respectively. This ratio is known as the 'shape factor' and is a criterion of the efficiency of the pyrometer. The second method is based on the determination of response times with and without suction of two similar pyrometers, the criterion being the time taken for the temperature difference between the two instruments to reduce to one-tenth of its original value as the suction is applied to or removed from one of the pyrometers.—L. D. H.

Temperature Measurements in Metal Melts. E. Samal. (*Giesserei*, 1955, **42**, Jan. 20, 36–37). The methods of measuring the temperature of molten metal, including the optical pyrometer, are first reviewed. The advantages of using a dipping thermocouple element are then described and the design of such an element illustrated. The wiring, operation, and construction of an accurate portable temperature-measuring apparatus are described in detail and the measuring tolerances given.—R. J. W.

Instrumentation at Fairless Works. H. L. Russell and F. R. Ross. (*Iron Steel Eng.*, 1955, **31**, Dec., 134–138). The authors describe automatic furnace reversal, especially constructed immersion thermocouples, temperature-control instrumentation on recuperative soaking-pit furnaces, strip-rule chart recording, and temperature control for batch annealing.—M. D. J. B.

REFRACTORY MATERIALS

Ultrasonic Machining of Ceramics. J. A. Dickinson. (*Ceramics*, 1954, **6**, Dec., 450–453). The working and applications of the 'Sheffield Cavitron' at Reinhold-Geiger Inc. are described. It is an ultrasonic machining tool for very hard materials—plate glass, quartz, pottery, cermets, etc. D. L. C. P.

Studies in the System CaO—MgO—CO_2. (Part I). The Thermal Dissociation of Calcite, Dolomite and Magnesite. R. I. Harker and O. F. Tuttle. (*Amer. J. Sci.*, 1955, **253**, Apr., 209–224). The univariant pressure (CO_2)/temperature curves for the thermal dissociation of dolomite and magnesite have been determined up to 40,000 lb./sq. in. and of calcite between 100 and 500 lb./sq. in. With rising temperature, the order of dissociation to oxide + CO_2 under equilibrium conditions was found to be magnesite, dolomite, calcite. E. C. S.

Rammed Linings for Indirect Arc Furnaces. E. Lens, jun. (*Foundry*, 1955, **83**, Feb., 126, 128). A new method of lining Detroit indirect-arc furnaces by ramming a mullite cement around a collapsible steel former is briefly described.—B. C. W.

Practical Aspects of Silicon Carbide Wear-Resistant Linings. R. E. Wolfensperger. (*Blast Furn. Steel Plant*, 1955, **43**, Mar., 310–314). Examples are shown of successful use of silicon carbide linings in conditions of severe abrasion. The lining of a dust collector on a sinter machine and the elbow of a blast-furnace downcomer with silicon carbide bricks are described.—B. G. B.

Refractories for the Steel Industry. (*Ceramics*, 1954, **6**, Dec., 444–449; 1955, **6**, Jan., 488–494). The types of refractory used in the different parts of the Bessemer, open-hearth, electric-arc, and induction furnaces are indicated. D. L. C. P.

The Choice of Materials for Open-Hearth Furnace Roofs. H. M. Richardson and G. R. Rigby. (*Silicates Indust.*, 1954, **19**, Dec., 401–405). [In English]. The manufacture of silica and basic bricks, and the mechanical, slag-resistant, thermal and thermal-shock properties, texture, and density of both types of brick are discussed and compared. The technology of basic-brick production and development, as well as data on basic-brick performance, do not yet parallel those related to silica bricks, and more data and experience are required before the likely future trends in basic roofs can be assessed with some certainty.—P. F.

Acid-proof Furnace Linings and Acid-proof Stoneware. A. Wester and B. Aggeryd. (*Tidsskr. Kjemi, Bergvesen og Met.*, 1954, **14**, Dec., 183–191). [In Norwegian].

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Observations on the Communications of MM. Moutot and Sanna and Results on Accumulation Experienced at Uckange Dolveck. (*Centre Doc. Sid., Circ. Inf. Tech.*, 1955, **12**, (2), 403–405). The significance of results described in the previous two papers is discussed in the light of results on accumulation obtained at Uckange over the last 6 years.—T. E. D.

Performance of Blast-Furnaces with High Pressure Tops. L. Brož. (*Hutnické Listy*, 1955, **10**, (2), 67–73). [In Czech]. An analysis of the functions of high blast pressures is made with reference to experiences gained in Europe, America, and the Soviet Union. The expansion of high-pressure practice in Czechoslovakia at a greater pace is advocated.—P. F.

Some Remarks Concerning the Repair of Blast-Furnaces. H. Haniš. (*Hutník*, (*Prague*), 1955, **5**, (1), 12–14). [In Czech]. The principles of efficient organization and successful repairs are analysed.—P. F.

Economic Utilisation of Ferrous Scrap in Blast-Furnaces. J. Horák. (*Hutník*, (*Prague*), 1955, **5**, (2), 34–36). [In Czech]. Scrap from dynamo and transformer sheet steels, containing above 2% Si, can be utilized by charging into the blast-furnace when making foundry irons.—P. F.

A Possible Method of Controlling Blast-Furnace Operation by Gas Investigations. G. von Struve. (*Met. u. Giesserei Techn.*, 1954, **4**, Dec., 511–522). Two series of tests in a blast-furnace at the J. V. Stalin Steelworks to investigate the possibility of a close supervision of furnace operation by gas analyses are described. The sampling device and the method of operation are discussed and results are given. L. J. L.

Reduction of Iron Ores by Reformed Natural Gas. N. Tabata and R. Sato. (*Tetsu to Hagane*, 1955, **41**, Jan., 5–11). [In Japanese]. The reducing action of natural gas is weak, but increases greatly on reconstitution, owing to the presence of H_2 and CO. At low temperatures bog ore and hematite are reduced more rapidly, but at higher temperatures magnetite is reduced most rapidly.—K. E. J.

The Reaction of Carbon and Oxygen in Molten Iron. E. T. Turkdogan, L. S. Davis, L. E. Leake, and C. G. Stevens. (*J. Iron Steel Inst.*, 1955, **181**, Oct., 123–128). [This issue].

TREATMENT AND USES OF SLAGS

Utilisation of Cements containing Granulated or Crushed Slag for the Surfacing of Roads and Airfields in Belgium. L. Blondiau. (*Silicates Indust.*, 1955, **20**, March, 97–105). Slag-base cements are shown to be as applicable as Portland cements.—P. F.

History of the Developments of Foamed Slag Production in Great Britain to Date. M. Gallai-Hatchard. (*Silicates Indust.*, 1955, **20**, Jan., 13–24). [In English]. Developments of foamed slag production in the U.K. and Germany are surveyed, and new developments in manufacture are discussed. Reasons are given why, in the author's opinion, foamed slag will play a progressively increasing part in building.—P. F.

Is Blast-Furnace Slag Cement Liable to Fail to Set? How is One to Prevent it? L. Blondiau and Y. Blondiau. (*Silicates Indust.*, 1955, **20**, Jan., 32–35; Feb., 73–78). The function and use of lime in the prevention of failure to set, to which blast-furnace cements are liable, like Portland cements, is considered. It is shown that cements containing calcium sulphate in the state of low solubility induced by heat-treatment are not liable to setting failure, whereas cements containing it in the form of the semi-hydrate are. Progress in the production of blast-furnace slag cements in Belgium is surveyed.—P. F.

DIRECT PROCESSES

The Lubatti Electric Reduction Method. A. Pecorari. (*Radex Rundschau*, 1954, (4–5), 152–164). [In German and Italian]. A description is given of the operation of the Lubatti furnace, used for smelting powdery low-grade ores with coal dust, the steel being obtained direct from the ore without the intermediate pig-iron stage.—G. G. K.

Beneficiation of Magnetite Ore to a High Grade Concentrate, and Processing of the Latter to Sponge Iron at Persberg, Central Sweden. W. Lehnert. (*Z. Erz. u. Met.*, 1954, **7**, Sept., 383–386; Oct., 435–440). A description is given of the new mineral-dressing plant at Persberg which produces a high-grade concentrate for sponge-iron production. The throughput capacity of the plant is 930 tons/day, present throughput (in two shifts) is 600 tons/day. The process relies on several stages of magnetic separation (dry and wet) with stage grinding to avoid excessive comminution. A sponge-iron plant immediately adjacent to the dressing plant uses the Wiberg-Söderfors process. The latter is described and discussed. Production and cost data are compared.—E. C.

Chemico-Physical Reactions in the Renn-Process Rotary Furnace. H. Weidermann. (*Met. u. Giesserei Techn.*, 1954, **4**, Nov., 462–468). Iron nodules are produced in a cylindrical rotary furnace. The chemical and physical processes in the preheating, reducing, and balling-up stages, and the properties and composition of the product and the slag are discussed.—R. A. R.

PRODUCTION OF STEEL

The Small Converter in the Steel Casting Works. M. Guédras. (*Mét. Constr. Mécan.*, 1955, **87**, Feb., 103–104). The use of the converter in steel casting works is discussed and the advantages and disadvantages of the techniques are reported. B. G. B.

Production of Cast Steel in Small Converters. B. Bradáč and K. Večera. (*Slévárenství*, 1955, **3**, (2), 42–44). [In Czech]. By a triplex method, utilizing the cupola, the 1½-ton converter, and the basic electric-arc furnace, steels of the highest quality can be efficiently and economically produced. The features, advantages, and disadvantages of the method, and the chemistry of the conversion, in both basic and acid converters, are discussed.—P. F.

The Development of the Basic Converter Process in Europe. A. Descer, F. Vandestrick, and J. Wurth. (*Blast Furn. Steel Plant*, 1955, **43**, Jan., 45–53). The analysis and mechanical properties of steels made in the basic converter blown with air, oxygen-enriched air, and other gaseous mixtures are described. It is shown that the use of oxygen, oxygen–water-vapour blasts, and double slags enable the sulphur and nitrogen contents of the steel to be reduced lower than in O.H. steel. The steels produced are quite suitable for deep drawing.—B. G. B.

Combustion Process of Rich Gases and Open-Hearth Furnace Port End Design for Optimum Performance. E. Bolsi. (*Met. Ital.*, 1954, **46**, Nov., 413–416). The author shows the importance of rapidly mixing fuel and air to allow for maximum heat input to the furnace. The conditions for achieving this are discussed and a process is described which ensures correct mixing. The method makes it possible to vary the flame. Port-end design is discussed and operating data of a 50-ton furnace designed to meet these requirements are given.—M. D. J. B.

A Technical Method of Making Regenerator Calculations. O. Jenne. (*Radex Rundschau*, 1955, (1), 301–319). The temperature conditions in regenerators that cannot be established by a simple calculation can be determined on a linear basis by a simple operation. The necessary steps and the corrections required are facilitated by the special computation table which is presented and is applicable to all types of regenerators.—R. A. R.

Some Structural Improvements to the Maerz Open-Hearth Furnace. L. Ullsperger. (*Met. u. Giesserei Techn.*, 1954, **4**, Dec., 524–528). Alterations in ports and regenerators of Maerz furnaces are described. The length of port block protected by coolers was extended, and the regenerator chambers were enlarged with beneficial effects on production. L. J. L.

Automatic Control of Thermal Processes in Steelworks Furnaces from the Design Point of View. J. Spal. (*Hutnické Listy*, 1954, **9**, Dec., Supplement 25–31). [In Czech]. The designer's attention is drawn to several alternative possibilities of achieving control of a given variable, with a view to selection of the best one.—P. F.

Automatic Control of Thermal Processes in the Open-Hearth Furnace. J. Starý. (*Hutnické Listy*, 1954, **9**, Dec., Supplement 16–25). [In Czech]. The theory and practice of the principal automatic control systems (e.g. for the control of the fuel/air ratio and the pressure in the furnace) are considered.—P. F.

The Relative Merits of Low- and High-Sulphur Oil for Open-Hearth Steelmaking. C. A. Edwards. (*J. Iron Steel Inst.*, 1955, **181**, Oct., 138-147). [This issue].

Time Factor in Operating Open-Hearth Furnaces Improved by Cutting the Time for Periodical Repairs and Overhauling. L. Szalinski. (*Hutnik*, 1954, **21**, (12), 385–390). [In Polish]. The organization of repairs and overhauls of O.H. furnaces is described.—V. G.

On Activities of Co-existing Elements in Molten Iron (III). K. Sanbongi and M. Ohtani. (*Tetsu to Hagane*, 1954, **40**, Dec., 1106–1109). [In Japanese]. The activity of Mn in molten Fe–Mn was determined at 1590° C. from the e.m.f. of the cell Fe–Mn/SiO_2–MnO–CaO–MgO/Mn and estimated for the whole temperature range from the equation. The results indicate that the Fe–Mn binary solution behaves almost ideally over the whole range, and it is considered that the Fe–Ni and Fe–Co binary solutions also follow Raoult's law.—K. E. J.

On the Inductance and Current Displacement in Conductors of Large Melting Furnaces Carrying Heavy Currents. E. Kluss. (*Elektrowärme-Techn.*, 1955, **6**, March, 52–59). The theory of systems of parallel conductors is developed with special reference to application to industrial furnaces. It facilitates determinations of the currents in the various branches of the network, which is particularly useful if they should not all be independently measurable.—P. F.

The Three-Phase Transformer for a High Secondary Current Strength (Furnace Transformer). J. Müller. (*Maschinenwelt Elektrotechnik*, 1954, **9**, Nov., 335–339). The construction, circuit diagram, and performance of a multi-phase transformer suitable for use with an electric furnace is outlined.

Preparation of Boron Steel Under Borate-containing Slag. M. Hasegawa and Y. Nakamura. (*Tetsu to Hagane*, 1955, **41**, Jan., 11–17). [In Japanese]. Tests made in the laboratory and on a 2-ton Héroult furnace are reported. Low-chromium and low-manganese steels were made, the boron content being readily controlled and 30–50% reduction of B_2O_3 being achieved: 0·02–0·05% of boron in the steel gave optimum hardenability. No difference in quality was found in comparison with steel made by adding ferro-alloys.—K. E. J.

Improved Process Control Assures Economical Production of Extra Low-Carbon Cast Stainless. R. W. de Weese. (*Iron Age*, 1954, **174**, Oct. 14, 133–135). The production of 0·03% C stainless steel castings at Electric Steel Foundry Co., Oregon, is described. Scrap selection and oxygen lancing in the arc furnace (but not in the induction furnace) ensure the production of a very-low-carbon stainless steel with improved corrosion resistance due to minimum carbide precipitation. D. L. C. P.

Advancements in Induction Heating. G. W. Holz. (*Indust. Heating*, 1954, **21**, Nov., 2226–2232, 2372–2374). The author describes typical H. F. and L. F. induction furnace installations for ferrous and non-ferrous melting purposes.—A. D. H.

Experiences with the Use of Factory-made Crucibles for High-Frequency Furnaces. V. Batěk and V. Hruška. (*Slévárenství*, 1954, **2**, (12), 354–356). [In Czech]. The composition and design of the crucibles, replacing works-rammed containers, for use in 250- and 800-kg. furnaces, are described. The crucibles were found better and more economical in use. P. F.

High Frequency Induction Furnaces Boost Foundry Melting Capacity, Widen Range of Metals Handled. W. D. Latiano. (*Iron Age*, 1954, **174**, Oct. 28, 95–98). The plant and processes in the centrifugal casting foundry of the Sandusky Foundry and Machine Co., Ohio, are described. When the installation of H. F. induction melting equipment is completed 40,000-lb. ferrous castings will be possible.—D. L. C. P.

Increasing the Life of Ingot Moulds. O. Bohuš. (*Hutnik*, (*Prague*), 1955, **5**, (1), 3–5). [In Czech]. Major factors affecting mould life are discussed, and practical ways of increasing mould life are indicated.—P. F.

Relation between the Chemical Composition of a Melt Sample and that of the Final Product made from Deep Drawing Rimming Steel. B. Otta. (*Hutnik* (*Prague*), 1955, **5**, (3), 72–76). [In Czech].

Adding Lead to Steel, Here's How it's Done. R. F. Huber. (*Steel*, 1954, **135**, Oct. 25, 150–155). Information, not previously published, is given on the techniques used by Inland Steel Co. and its licensees to make leaded steels. Carefully prepared lead shot is blown with a lead air-blast gun into the steel stream running into the mould to give 0·15–0·35% lead in the finished steel.—D. L. C. P.

Steel Ladle Linings. G. Ziliani. (*Met. Ital.*, 1954, **46**, Dec., 450–459). Technical and statistical data are given on the behaviour of steel ladle linings. The study which was undertaken by a specially appointed committee covers such items as refractory qualities, life, and the design of ladles. M. D. J. B.

Casting Steel by the Mile. (*Canad. Metals*, 1954, **17**, Nov., 18–20); **Continuous Casting Installation for Stainless and Alloy Steels.** (*Engineer*, 1954, **198**, Dec. 31, 926–928); **Modern Steel Plant Teams Continuous Casting with Planetary Mill.** E. C. Beaudet. (*Iron Age*, 1954, **174**, Nov. 4, 113–120). Recently installed equipment for processing stainless steel, at the Welland (Ontario) plant of Atlas Steels Ltd. is described. A Rossi-Junghans machine, designed and installed by Koppers Co. for casting alloy steel slabs and billets up to 6 × 24 in. is operating. The quality of the steels produced is said to be comparable to that of conventionally produced materials; 5½ × 7½ in. billets have been cast at up to 75 in./min. and 5½ × 21½ in. slabs up to 40 in./min.—D. L. C. P.

Grain Size Control of Killed Steel by Addition of Aluminium. T. Kato and T. Ito. (*Tetsu to Hagane*, 1954, **40**, Nov., 1051–1059). [In Japanese]. Trials were made with high- and low-carbon steels made in several ways. AlN was found to be important in retarding austenitic grain growth by Al addition, but Al_2O_3 reduced its effect in fine-grained steel. In coarse-grained steels, Al_2O_3 and sulphides had some retarding effect. Duplex grains were formed at the transition stage of grain growth and by Al_2O_3 segregation. Deoxidation in the basic O.H. would be valuable in stabilizing grain size. K. E. J.

Notes on the Solidification and Rimming of Basic-Bessemer Ingots Weighing 4·6 Tons. J. Duflot and A. Richard. (*Rev. Mét.*, 1954, **51**, Sept., 623–657). Experiments are described

for studying the solidification of basic-Bessemer steel in ingot moulds and to gather information on the formation of skin blowholes caused by the rimming action. Appropriate methods of removing the blowholes from the surface of the ingots are also given.—G. E. D.

Saving Steel by Reducing the Size of Scrapped Parts of Ingot Tops. N. Chvorinov. (*Hutník, (Prague)*, 1955, **5**, (2), 36–43). [In Czech]. On the basis of pilot and works experiments involving several thousand tons of steel cast into 3½-ton ingots, it is shown that a 5–8% average reduction in the loss of steel, due to piping arising from shrinkage contraction, can be achieved by heating the ingot heads with oxygen burners during solidification.—P. F.

Study of the Variation of the Principal Chemical Constituents as a Function of Position of Sampling. Hentz. (*Centre. Doc. Sid., Circ. Inf. Tech.*, 1955, **12**, (1), 193–200). Distribution of carbon, phosphorus, and sulphur in four ingots of different types was studied. Results are tabulated and also shown diagrammatically.—T. E. D.

PRODUCTION OF FERRO-ALLOYS

Recent Developments in Manganese Supply. R. C. Buehl. (*Amer. Inst. Min. Met. Eng., Proc. Nat. O. H. Comm.*, 1954, **37**, 187–192). The author briefly reviews recent developments in methods of manganese recovery from slags and low-grade ores. He considers first the concentration of low-grade ores, and then discusses processes involving chemical solution and precipitation, including the Dean ammonium carbamate process, the Nissen nitric-acid process, and the electrolytic method. Finally attention is given to pyrometallurgical processes involving either selective reduction of iron and phosphorus or selective oxidation of manganese.—G. F.

Ferromanganese Gas Cleaning at Duquesne Works, United States Steel Corporation. C. H. Good. (*Amer. Inst. Min. Met. Eng. Proc. Blast Furn. Coke Oven, Raw Mat. Comm.*, 1954, **13**, 169–178). At Duquesne Works, the ferromanganese blast-furnace gas contains 8–12 grains/cu. ft. of fume, average particle size 0·3μ. In the gas-cleaning plant, the gas is first passed through a conditioning tower where it is humidified, and then through a dry-plate electrostatic precipitator. Expected cleaning efficiency is 98%.—G. F.

The Rotating Hearth Furnace. B. Ydstie. (*Canad. Min. J.*, 1954, **75**, Dec., 56–58). Development of the rotating hearth submerged-arc electric smelting furnace is traced. The principle was first applied by Tennessee Valley Authority to a 1000-kW. test furnace for phosphorus, at Wilson Dam in 1947. About 10 covered furnaces with rotating hearths are now in operation, including furnaces for ferro-manganese and silico-manganese. Power consumption is considerably lower in rotating hearth furnaces than in stationary ones.

T. E. D.

FOUNDRY PRACTICE

Semi-Steel. K. H. Coombs. (*Engineer Foundryman*, 1955, **19**, Jan., 43).

Chill Testing. A. P. Alexander. (*Engineer Foundryman*, 1955, **19**, Jan., 41–42). A brief account is given of wedge and enforced chill testing as a means of foundry control.

A. D. H.

Molding System is Highly Automated. R. H. Herrmann. (*Foundry*, 1955, **83**, Jan., 110, 113, 116, 118). A description is given of a new closed circuit mechanised moulding system recently installed at the Eberhard Mfg. Division of the Eastern Malleable Iron Co., Cleveland. Sand is mixed and fed to the system automatically and the pouring is done by remote control. Rate of production is 300 moulds/hr.—B. C. W.

Simplifying the Work Can Reduce Costs. W. C. Cheek. (*Foundry*, 1955, **83**, Feb., 78–81, 238–240). The principles of work simplification in the foundries are discussed, with particular reference to the reduction of costs.—B. C. W.

The Use of Median Diagrams for the Control of Technological Processes. R. Krzeszewski. (*Przeglad Odlewnictwa*, 1955, **5**, (1), 5–9). [In Polish]. The application of statistical methods for the control of the melting process in cupolas is discussed.—V. G.

Economic Considerations in Refractory Ladle Practice. J. H. Rickey, Jun. (*Trans. Amer. Found. Soc.*, 1954, **62**, 236–242). Various types of ladle refractories are discussed, together with the methods that can be used to prepare linings for the different ladles that may be used in foundry practice.—B. C. W.

Protective Equipment for Foundrymen. R. L. Berger. (*Trans. Amer. Found. Soc.*, 1954, **62**, 425–426).

Principles of Effective Maintenance for Foundry Ventilation and Dust Collecting Systems. K. M. Smith. (*Trans. Amer. Found. Soc.*, 1954, **62**, 156–162). The steps that should be taken, both in original design and in subsequent operation, to provide for the effective maintenance of foundry ventilation and dust collection systems are discussed.—B. C. W.

Fundamentals Make Better Castings. L. L. Clark. (*Trans. Amer. Found. Soc.*, 1954, **62**, 176–180). The fundamentals of good sand practice are reviewed and discussed in general terms.—B. C. W.

A.F.S. Safety, Hygiene, and Air Pollution Program. J. R. Allen. (*Trans. Amer. Found. Soc.*, 1954, **62**, 299–300). The work of the committees responsible for implementing the safety, hygiene, and air pollution programme of the American Foundrymen's Society is reviewed.—B. C. W.

Value of the Safety Program to the Foundry. E. C. Hoenicke. (*Trans. Amer. Found. Soc.*, 1954, **62**, 301–303). The economic and humanitarian aspects of foundry safety are briefly considered and the steps that can be taken to prevent accidents in the foundry are outlined.—B. C. W.

Training in Accident Prevention. T. A. Kraklow. (*Trans. Amer. Found. Soc.*, 1954, **62**, 381–382).

Improved Design of the Base of Centrally Charged Cupolas. J. Plch. (*Slévárenství*, 1955, **3**, (3), 77–78). [In Czech].

Hot Blast Systems. G. P. Phillips. (*Foundry*, 1955, **83**, Jan., 92–95, 211–212, 214–216). Various U.S. and Continental designs for cupola hot-blast systems are described and discussed, and the advantages and disadvantages of the recuperative and the externally fired type are considered.

B. C. W.

Cupolas in Steelworks Practice. (*Found. Trade J.*, 1955, **98**, Mar. 3, 237–240). Recently published data on the use of cupolas in conjunction with O.H. furnaces are reviewed and discussed.—B. C. W.

Air Pollution Control Equipment for the Cupola. D. E. Gilchrist. (*Trans. Amer. Found. Soc.*, 1954, **62**, 473–480). The problem of air pollution by cupolas is discussed and the various types of equipment available for preventing such pollution are reviewed. The installations discussed include centrifugal and inertia types, centrifugal scrubbers, bag filters, electrostatic filters, waste-heat recuperators, and wet washers.—B. C. W.

Improving the First Iron Tapped by the Oxygen-Enrichment of the Blast of Cupolas with a Fore-Hearth. W. Ballhouse. *Giessereitechn.*, 1955, **1**, Jan., 2–4). The author reports on two years of experience of oxygen-enrichment of cupola blast to improve the first iron tapped. Reference is made to the success of the process in other places, especially in the U.S.S.R., as described by M. J. Saslawsky.—L. J. L.

Melting, Desulphurisation, and Refining of Iron in the Cupola. F. Rodriguez–Yufera y Muñoz. (*Anal. Mec. Elect.*, 1955, **32**, Jan.-Feb., 3–22). [In Spanish]. This article concludes a series of three which were published in the *Anales*, 1953, **30**. A detailed thermodynamic study of the slag–metal reactions in relationship to refining and desulphurization is given. A series of curves describing the reduction of the sulphur content of the metal with time as a function of the slag composition are included. It is concluded that the quality of the product depends exclusively upon the refining action of the slag. The use of hot blasts, oxygen enrichment of the blast, and refining in the ladle by oxygen lances are briefly discussed.—P. S.

Properties of Cast Iron at Elevated Temperatures. J. R. Kattus. (*Foundry*, 1955, **83**, Feb., 96–97, 230–232, 234, 237). The literature on the properties of cast iron at elevated temperatures is reviewed and some preliminary data on the softening of twelve cast irons at 310° and 340° C. are presented and discussed. The aspects concerned in the literature review include growth, short-time elevated temperature tensile properties, creep properties and thermal shock resistance.

B. C. W.

Methods of Introducing Magnesium or Electron Alloy During Production of Spheroidal Iron. M. Pachowski. (*Przeglad Odlewnictwa*, 1955, **5**, (1), 9–16). [In Polish]. A survey of methods used for inoculation of cast iron with magnesium or magnesium alloys is given.—V. G.

Industrial Production of Spheroidal Cast Iron under Pressure. V. Otáhal. (*Slévárenství*, 1955, **3**, (1), 2–6). [In Czech]. Pilot plant and works experiments, using autoclaves, are described. At a pressure of 4·5 to 5·5 atm. and an inoculation temperature of 1350° C., 0·1%Mg is sufficient for irons containing 0·03%S; 0·2%Mg is required for irons with 0·14%S. The design of the equipment, as used on the industrial scale, is considered.—P. F.

Production of Inoculated Cast Irons in the V. M. Molotov Iron Works in Třinec. M. Stárek. (*Slévárenství*, 1955, **3**, (2), 36–41). [In Czech]. Results of experiments with the use of spheroidal graphite irons on a large scale are described. Metallographic structures and mechanical properties of the irons inoculated with magnesium, FeSi (75%), and cast-iron filings were entirely satisfactory, and 17 tons of cast iron were successfully inoculated and cast into rolling-mill rolls weighing 16 tons.—P. F.

Studies in Cement-Sand Steel Casting Methods. W. Eitel and N. Köppen. (*Giesserei Technisch-Wissenschaftliche Beihefte*, 1954, Dec., (14), 701–707). A microscopical investigation of the reactions between cement-sand moulds and steel slag is reported. The cement-sand mould in contact with the cast steel has a zoned construction. In this contact zone, a magnetite–fayalite layer is formed, which has a low viscosity enabling the mould to be easily 'burnt' from the casting.—R. J. W.

Iron and Steel Roll Production. (*Foundry Trade J.*, 1955, **98**, Jan. 27, 101–103). The development of iron and steel roll production at R. B. Tennent Ltd. is reviewed and the new arc furnace recently installed as part of an expansion programme is briefly described.—B. C. W.

Modern Manufacture and Use of Cast Rolling-Mill Rolls. F. H. Allison, jun., and C. E. Peterson. (*Iron Steel Eng.*, 1954, **31**, Dec., 68–76). The methods of producing cast-iron and cast-steel rolls are described. Moulding and casting techniques are discussed and details are given of the compositions of the various types of rolls commonly used in the iron and steel industry.—M. D. J. B.

Casting Tolerances Keyed to a Target. (*Steel*, 1954, **135**, Oct. 11, 116–117). The production of high-precision 600-lb. cast alloy-steel shells is described. Bore tolerance is ± 0·025 in.; core preparation and the casting and finishing procedure are explained.—D. L. C. P.

The Present State of Exploitation of Rájec Foundry Sands. J. Stejskal. (*Slévárenství*, 1955, **3**, (3), 65–67). [In Czech]. Possibilities for improving the quality and reducing fluctuations in compositions in foundry sands obtained from the largest Moravian deposits near Blansko are discussed.—P. F.

Cut Production Costs with Sand Reclamation Unit. H. Chappie. (*Amer. Foundryman*, 1955, **27**, Jan., 48–49). The wet-sand reclamation unit installed at the National Supply Co., Torrance, Calif., is briefly described and comparative moulding sand costs are calculated.—B. C. W.

Processing Molding Sand. H. W. Dietert. (*Trans. Amer. Found. Soc.*, 1954, **62**, 1–32). In the Charles Hoyt Annual Lecture those aspects of the preparation and processing of foundry sand that lead to improved casting quality and reduced casting cost are considered in detail.—B. C. W.

A Study of the Moulding and Manufacture in a Cast Iron Foundry of a Casing of a Transmission Gear Box. (*Fonderie*, 1954, Dec., 4285–4291). A detailed and illustrated description is given of the methods of moulding and coring used for a gear-box casing.—B. C. W.

Planning Influences Pattern Quality. R. H. Herrmann. (*Foundry*, 1955, **83**, Feb., 100–105). A description is given of the procedure followed at the Motor Patterns Co., Cleveland, for the production of high-quality patterns and pattern equipment.—B. C. W.

Practical Applications for Expansion Plaster. O. H. Harer. (*Trans. Amer. Found. Soc.*, 1954, **62**, 389–392). The characteristics of the new gypsum cements that expand uniformly in all directions on setting are outlined, and their applications for pattern making in the foundry are discussed. By adjusting the plaster/water ratio the setting expansion can be controlled and results to illustrate this are given.—B. C. W.

Use of Rice and Oat Hulls as Riser Insulation. S. L. Gertsman and R. K. Buhr. (*Foundry*, 1955, **83**, Feb., 92–94). Results are presented of experiments on the use of rice and oat husks as anti-piping, insulating compounds. No carbon segregation was observed with either material and no advantage was gained by grinding or screening. The layer of hulls should be at least 3 in. deep. Both rice and oat husks may be seriously considered as riser insulation compounds because of their relatively low cost.—B. C. W.

Improve Mould Feeding Systems to Cut Casting Scrap. W. M. Halliday. (*Iron Age*, 1955, **175**, Jan. 27, 82–85). Principles for the proper design and location of runners, feeders, and gating systems for sand moulds are explained.

Malleable Gating. L. Winings. (*Amer. Foundrymen*, 1955, **27**, Jan., 35–40). Experiences in gating malleable iron castings at the Wagner Malleable Iron Co., Decatur, Ill., are then discussed with reference to various practical examples.

The Study of Vertical Gating. K. R. Grube and J. G. Kura. (*Trans. Amer. Found. Soc.*, 1954, **62**, 33–42). Using water in transparent moulds a study has been made of the design of vertical gating systems with particular reference to the avoidance of turbulence and air-entrainment. A satisfactory design of gate and runner has been worked out. It is intended to verify the laboratory results with tests made on aluminium alloy castings.—B. C. W.

Valves for Moulding Machines. C. V. Jahle and R. Orban. (*Gjuteriet*, 1955, **45**, Jan., 6–11). [In Swedish]. The design, use, installation, and maintenance of the various types of valves used on air-operated moulding machines are described.

What High-temperature Tests Tell About Core Knockout. V. M. Rowell. (*Amer. Foundryman*, 1955, **27**, Jan., 57–59). A test casting designed to predict the difficulties likely to be experienced in knocking out cores is described. It is concluded that the hot compressive strength or the retained compressive strength of baked cores may be used to determine the order of core knock-out difficulty, provided that the cores are heated under their own atmosphere in gastight containers.

What is Stickiness in Core Sand Mixtures? W. H. Buell. (*Trans. Amer. Found. Soc.*, 1954, **62**, 131–137). The problem of stickiness in core sands is briefly outlined and the results so far obtained on this problem are reviewed. Some data on the effect of cereal/water ratios on the green and dry strength of cores are also given.—B. C. W.

Use of Blow-in Core Driers. R. W. Wendt. (*Trans. Amer. Found. Soc.*, 1954, **62**, 427–428). The method of blowing cores directly into dryers is described and briefly discussed.

Large Cast-Iron Pipe Manufacture—Pattern Control. J. Bell. (*Found. Trade J.*, 1955, **98**, Feb. 24, 203–204). The pattern-store layout and the organization required for checking the pattern components needed for large pipe production are briefly described.—B. C. W.

Large Cast-Iron Pipe Manufacture—Loam-Block Pattern. S. Lloyd. (*Found. Trade J.*, 1955, **98**, Feb. 24, 204–205). The method of preparing a loam-block pattern for the manufacture of special cast-iron pipes is briefly described.—B. C. W.

Large Cast-Iron Pipe Manufacture—Shell Cores for Large-Diameter Special Pipes. G. Brown. (*Found. Trade J.*, 1955, **98**, Feb. 24, 205–207). A method for making resin-bonded hollow cores for large-diameter special pipes is briefly described.—B. C. W.

The Manufacture of Housings for the Chemical Industry from Patterns. H. Stark. (*Giesserei*, 1954, **41**, Dec. 9, 677–679). The manufacture of a mould for a casing 120 cm. outside dia. × 82 cm. high is described in detail. This casing is made in two parts. The manufacture of the core and final assembly of the mould are described separately.—R. J. W.

Frozen Mercury Castings. (*Canad Metals*, 1954, **17**, Nov., 29–32); **Precision Casting with Frozen Mercury. The Mercast Process.** G. Genin. (*Rev. Gén. Mécan.*, 1954, **38**, Nov., 409–414). The Mercast process of precision casting is essentially similar to the lost-wax process except that the pattern is made by freezing mercury in a master mould. The frozen mercury pattern is then 'invested' and removed from the investment by allowing it to warm up, melt, and run out of the gates. Details of the process are given.—B. G. B.

Growing Competence in High Pressure Moulding. W. R. Adams. (*Canad. Metals*, 1954, **17**, Dec., 34–38). The latest developments in high-pressure moulding for the production of high-quality castings in large and small foundries are discussed.—B. G. B.

Centrifugal Casting of Tubular Steel Bodies. F. Wiesner. (*Slévárenství*, 1955, **3**, (2), 44–46). [In Czech]. The theory and several methods of centrifugal casting and casting machines rotating about horizontal or vertical axes are discussed.—P. F.

Sixty Year Jubilee of the N.V. Doetinchemsche Iron Foundry. (*Metalen*, 1954, **9**, Dec. 15, Supplement "Handel en Industrie", 210–213). [In Dutch]. The article reviews briefly some developments in the history of this foundry where centrifugally cast pipes are now made.—R. S.

Some Properties of Phenolic Resin Core Binders. C. E. Schubert. (*Foundry*, 1954, **82**, Dec., 100–101, 248–251). The results of tests on cores made with fine commercial phenolic resin binders are presented and discussed. The properties determined were the tensile strength of cores baked for different times and different temperatures, the loss in strength of cores after reheating and as a result of moisture absorption, and the total amount of core gases given off at 740° C.—B. C. W.

Shell Moulding Is Easier. R. Olson. (*Foundry*, 1955, **83**, Jan., 76–79, 148, 150). The new equipment and techniques to make shell moulding an easier and less expensive process at the Production Pattern and Foundry Co., Chicopee, Mass., are described and discussed. By using a phenolic resin cement to bond the mould halves together most moulds can be poured horizontally, so avoiding the use of a back-up material.—B. C. W.

Producing Shell Cores on a Production Basis. F. Schumacher. (*Foundry*, 1955, **83**, Feb., 178, 181). The advantages of shell cores are outlined and a process for blowing such cores using a mandrel to control the wall thickness and inside contour is briefly described.—B. C. W.

The Shell Moulding Process. D. N. Buttrey. (*J. Inst. Prod. Eng.* 1954, **33**, Nov., 634–641)., A comprehensive account of the shell moulding process is presented. The technique is most useful in those industries where long runs of a particular casting are required. For jobbing work the process has little value.—B. G. B.

Shell Moulding Materials: Their Testing and Properties. D. A. Taylor. (*Brit. C. I. Res. Assoc., J. Res. Dev.*, 1954, **5**, Dec., 502–516). A description is given of an apparatus designed for the rapid production of specimens for test purposes in which the dimensions of the test piece, time of cure, and temperature can be accurately controlled. Results obtained, which show the effects of curing temperature, time, resin content, clay content, and the properties of various shell moulding sands are given and discussed.—B. G. B.

Mechanized Shell Molding. F. E. Murphy. (*Amer. Foundryman*, 1955, **27**, Jan., 43–45). A description is given of the mechanized shell moulding bronze foundry of the Walworth Co., South Boston, Mass. and the operation of the fully automatic moulding making machine.—B. C. W.

Casting Quality, Ease of Mechanization Key Shell Mold Advantages. W. F. Bye. (*Iron Age*, 1954, **174**, Nov. 18, 147–150; Nov. 25, 98–101). The technique of shell moulding is described and characteristics of this method of casting are considered.—D. L. C. P.

Inexpensive Shell Molding and Coremaking Machine Handles Job Work. W. G. Patton. (*Iron Age*, 1954, **174**, Oct. 7, 130–132). The simple 'Gee' shell-moulding machine for experimental or job casting work is described.—D. L. C. P.

Pattern Equipment for Shell Molding. O. C. Bueg. (*Trans. Amer. Found. Soc.*, 1954, **62**, 195–198). The problems of patternmaking for the shell moulding process are briefly discussed. The aspects considered include accuracy, thermal expansion, draft, gating, push-out pins, and heating.—B. C. W.

Solidification Process of Cast Iron. I. Igarashi, T. Harigome, K. Saito, K. Kamimura, I. Kikuchi and A. Okuda. (*Tetsu to Hagane*, 1955, **41**, Feb., 107–110). [In Japanese]. Solidification was studied by means of the microstructures and shapes of the cooling curves obtained from hypoeutectic Fe–C alloys melted in a reducing atmosphere and quenched at a desired temperature. The effects of Si, Mn, S, O, W, Cr, and Te were investigated.—K. E. J.

Steel Castings' Defects. R. A. Bonstred. (*Engineer Foundryman*, 1954, **19**, Dec., 51–57). Theoretical and practical factors involved in the formation and prevention of blowholes, pinholes, shrinkage defects, burning on, hot tears, and expansion scabs are discussed.—A. D. H.

Original and Secondary Defects in Castings. J. Přibyl. (*Slévárenství*, 1955, **3**, (3), 69–72). [In Czech]. The nature of faults in castings and the relation between different types are considered. It is shown that removal of primary faults generally precluded formation of secondary ones. A systematic list of primary and associated secondary faults is given.—P. F.

Another Look at "Expansion"-type Scabs. D. C. Williams. (*Found. Trade J.*, 1955, **98**, Feb. 17, 169–174). A large number of literature references are cited to demonstrate that expansion-type scabs have been attributed to a variety of causes. It is suggested that the scabs are formed by the exudation of liquid alloy from a casting section just before final solidification, and that they may be eliminated by ensuring that final solidification occurs well within the casting.—B. C. W.

Cooling Castings After Shake-out. T. J. Glaza. (*Amer. Foundryman*, 1955, **27**, Jan., 46–47). The transport and cooling of castings from shake-out to the cleaning room is briefly discussed and some curves are presented to show the cooling of castings under different conditions.—B. C. W.

The Deoxidation of Foundry Iron Melts by Subsequent Treatment and Its Influence on the Structure. H. Schiffers. (*Giesserei*, 1954, **41**, Dec. 9, 661–672; Dec. 23, 693–699). The general behaviour of gases in cast iron is first considered. The effect of the usual deoxidation media, especially as ladle additions, on the melt and the texture of the cast iron is described. The deoxidizing effect of silicon, magnesium, aluminium, and other chemical elements are treated separately. The influence of deoxidizing media with low boiling points on the melt and on the surface tension is discussed in terms of the change in partial pressure produced by deoxidation, both at ordinary pressures and *in vacuo*. The effect of deoxidation on desulphurization and on the carbon content in cast iron is considered in detail, a contribution being made to the knowledge of the crystallization of spheroidal graphite.—R. J. W.

Solidification Sequences and Their Significance. I. C. H. Hughes. (*Brit. C. I. Res. Assoc., J. Res. Dev.*, 1955, **5**, Feb., 518–536). Some essential features of solidification and the study of solidification in small samples and in castings are briefly described. The behaviour of the commoner types of cast iron and the effects of varying major composition are indicated. The shrinkage characteristics of flake graphite and nodular graphite irons and their differing solidification sequences are discussed.—B. G. B.

The Solidification of Castings in Relation to Their Soundness. J. H. Gittus and I. C. H. Hughes. (*Brit. C. I. Res. Assoc., J. Res. Dev.*, 1955, **5**, Feb., 537–554). The modes of solidification of (*a*) low-phosphorus flake graphite, (*b*) high-phosphorus flake graphite, and (*c*) nodular graphite cast irons have been studied by means of microscopic examination of 2-in. dia. sand-cast bars quenched at various times during solidification. The temperature conditions during solidification were also studied. The information obtained reveals differences in the modes of solidification of these irons that may have an important bearing on their shrinkage characteristics.—B. G. B.

Structural Changes During the Annealing of White Cast Iron with High S : Mn Ratios, Including the Formation of Spherulitic and Non-Spherulitic Graphite and Changes in Sulphide Inclusions. A. Hultgren and G. Östberg. (*Jernkontorets Ann.*, 1955, **139**, (1), 1–50). [In Swedish]. Examination of the microstructures of quenched specimens indicated the mechanism of formation of dispersed graphite flake nests, compact graphite nests, and graphite spherulites during annealing at 900–1150° C. of various white cast irons. It was observed that an iron or manganese sulphide inclusion could serve as a nucleating particle for a graphite spherulite, provided that the radial texture established was preserved during further radial growth, this being possible when sufficient sulphur or hydrogen are present to retard the *a*–axis growth of the graphite in relation to the *c*–axis.—G. G. K.

A Fracture Test-piece for Cast Irons During Cooling. E. Gabel. (*Fonderie*, 1954, Dec., 4272–4280). The problem of choosing a test piece to determine the susceptibility of thin-section castings to fracture during cooling is discussed and the development of a satisfactory design of casting is described. It is concluded that the cooling rate of the test casting must be standardized to give reproducible results. Experiments on cast irons show that decreasing either the phosphorus, silicon, or manganese content decreased the susceptibility to cracking.—B. C. W.

HEATING FURNACES AND SOAKING PITS

Furnaces with Continuous Hearths. (*Mét. Contr. Mécan.*, 1955, **87**, Apr., 299–302). A short illustrated account of heat-treatment furnaces which are fitted with the continuous-belt type of hearth is presented.—B. G. B.

Sixty Cycle Induction Heating For Forging and Extrusion. J. A. Logan. (*Indust. Heating*, 1955, **22**, Feb., 282–294, 423–426, 442–446). An installation for heating 7-in. dia. steel billets is described.—A. D. H.

High Speed Heating of Steel for Plastic Deformation. E. G. de Coriolis. (*Blast Furn. Steel Plant*, 1955, **43**, Mar., 320–324, 351). An estimate is made of the time required to heat cylinders of carbon steel to a core temperature of 2200° F. under three different conditions of heating.—B. G. B.

Maintenance of Slag Bottom Soaking Pits. J. A. Warchol, jun. (*Iron Steel Eng.*, 1955, **31**, Dec., 121–122). The author describes maintenance procedure on soaking pits at the Lukens Steel Co. Methods of controlling slag accumulation, the scheduling of pits for slag removal and the procedure for removing the slag are described.—M. D. J. B.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Homogenisation Treatment Applied to Cast and Forged Steel. A. Hencks. (*Rev. Tech. Luxembourg*, 1955, **47**, Jan.-Mar., 11–24). The nature of segregation during cooling in steel castings is explained. The influence of the primary grain size on chemical heterogeneity is discussed and diffusion phenomena are considered. The construction of diagrams for use in homogenizing heat-treatment is reviewed.—B. G. B.

Continuous Furnaces with Tubular Muffles. (*Mét. Constr. Mécan.*, 1955, **87**, Mar., 209–211). A design of heat-treatment furnace is described which employs heat-resistant tubes as muffles and through which the material for treatment is passed. The heat-treatment of tubes and wire of mild steel and stainless steel is described. Depending on the condition of treatment, heat-resisting steel or refractory tubes are used for the furnace construction.—B. G. B.

Outside Facilities Lower Plant Heat Treating Costs. E. M. Olson. (*Iron Age*, 1955, **175**, Jan. 27, 78–79). An account is given of the circumstances in which a meter manufacturer found it advantageous to send out steel gears, shafts, bearing parts, and production tools to a commercial heat-treating firm.—D. L. C. P.

Heat Treatment of Ferrous Metals: Some Recent Installations Reviewed. (*Brit. Steelmaker*, 1955, **21**, Feb., 50–58). The salient features of a number of recent heat-treatment installations are described. These include electric and gas-fired units, high-frequency induction heated furnaces, and various continuous and semi-continuous furnaces representing the most up-to-date products of the leading British manufacturers.—G. F.

New Heat Treating Equipment in Great Britain. T. Bishop. (*Metal Progress*, 1955, **67**, Jan., 154–158). The 'drip-feed' method of obtaining a carbonizing atmosphere is described. A process using the partial combustion of gas with oxygen to leave sufficient hydrogen and carbon monoxide in the products of combustion to prevent scaling during heating, is explained.—B. G. B.

Heat Treatment and Processing. J. Walker. (*Fuel Econ. Rev.*, 1955, **33**, 63–70). The article is primarily intended to demonstrate the advantages obtainable by employing the modern insulating bricks now available for furnace construction. Economies and increased productivity result from: (*a*) Low heat loss to the furnace structure; (*b*) low conduction heat loss to air; (*c*) light weight foundations, steelwork, and lifting gear are possible; (*d*) simple suspension; (*e*) larger working spaces; (*f*) high resistance to protective atmospheres; and (*g*) good electrical resistance.—D. L. C. P.

On the Case Hardening of Steels by Modified Gas Utilizing O_2. (I). M. Okamoto and N. Shirai. (*Tetsu to Hagane*, 1955, **41**, Feb., 127–133). [In Japanese]. Optimum conditions were determined for the production of gases containing C_2N_2O by introducing $K_4Fe(CN)_6$ in atmospheres of air and O_2. The carbonitriding effect of these gases was found to be good for rimmed as well as killed steels.—K. E. J.

On the Carburizing of Steel in Air-Propane Atmosphere. M. Komo, T. Hara, A. Adachi, and S. Yamada. (*Tetsu to Hagane*, 1955, **41**, Feb., 124–126). [In Japanese]. A carburizing atmosphere was produced by conversion of a mixture of propane (a petroleum by-product) and air: this contained considerable amounts of the reducing gases CO and H_2. It was successfully used to carburize steel, and, with proper adjustment of the H_2O content, to control surface carbon content.—K. E. J.

Practical Applications of Dew Point Measure and Control. O. E. Cullen. (*Indust. Heating*, 1955, **22**, Jan., 52–60, 201–203). The theory and practice of controlling the carbon potential furnace atmospheres by dew-point measurement is explained.—A. D. H.

Some Considerations on the Action of Energizers in Solid Carburizing Agents. H. Schrader. (*Tisco*, 1954, **1**, Oct., 147–155). The composition of solid carburizing agents and the energizing additions are discussed. The energizing effects of barium and calcium compounds are compared. The effect of oxide and carbonate energizers depends on: (i) The oxygen content which goes to form CO; and (ii) the heat of dissociation of oxides and carbonates to the metallic state and CO, and the formation of alkali and alkaline earth carbides. The action of nitrogen-containing energizers is explained.
L. E. W.

Localised Surface Hardening. H. Bos. (*Tecn. Indust.*, 1955, **33**, Feb., 177–180). [In Spanish]. Techniques of oxy-acetylene flame-hardening are described and typical applications are illustrated. About 40 suitable carbon and alloy steels are listed; the majority contain 0·35–0·50% carbon.
P. S.

Effect of Microstructure on Flame Hardenability of Grey Cast Iron. H. W. Grönegress. (*Stahl u. Eisen*, 1955, **75**, Jan. 27, 89–95). The size of the graphite flakes determines whether grey cast iron can be flame-hardened. Coarse flakes result in burning and in spalling of the hardened layer during grinding. The graphite should not be larger than A.S.T.M. 5 for flame hardening. Spheroidal graphite iron is excellent for flame-hardening because the ferrite of the matrix dissolves carbon from the spheroids. Some applications of flame-hardening to cast-iron parts are described.—T. G.

Dissociated Ammonia (Furnace Atmosphere). M. R. Ogle. (*Indust. Heating*, 1955, **22**, Feb., 264–272, 430). Equipment, applications, and costs for furnace atmospheres produced from liquid ammonia are discussed.—A. D. H.

Heat Treatment—Controlled Atmospheres. (*Machine Shop Mag.*, 1955, **16**, Jan., 44–46). The use of controlled atmospheres in the heat-treatment of steels and copper, and the advantages thus gained, are briefly discussed.—M. A. K.

Mechanized Furnace Improves Heat Treatment of Grey Iron. (*Foundry*, 1955, **83**, Feb., 152–153, 155). A description is given of a mechanized direct gas-fired furnace used for heat-treating grey iron castings, which are moved through the furnace and slow-cooling zone by a pusher mechanism.
B. C. W.

Electrical Control for Continuous Annealing Line. P. A. Travisano. (*Blast Furn. Steel Plant*, 1955, **43**, Mar., 305–309, 314). An account of the electrical controls for the continuous annealing of tinplate steel at the Fairless Works of the United States Steel Corp. is given.—B. G. B.

Batch Softening Stainless Steel Strip. (*Metallurgia*, 1955, **51**, Feb., 100). A brief account is given of an electrically heated bell-type furnace installed at the Shepcote Lane Rolling Mills Ltd., Sheffield, for the batch softening of coiled stainless-steel strip at 780–800° C. Each furnace base can carry two coils of strip with a total weight of 20,000 lb.
B. G. B.

Silicon Carbide Radiant Tube Furnace Speeds Wire Patenting Operation. (*Indust. Heating*, 1955, **22**, Feb., 308–318). A patenting furnace rated at 3000 lb./hr. in which heating is accomplished by silicon carbide radiant tubes is described.
A. D. H.

Heat Treatment of "Permite" Automotive Engine Valves in Mechanized Salt Baths. W. Klayer. (*Indust. Heating*, 1955, **22**, Feb., 252–260). The equipment and operation of a mechanized system for heat treating valves containing 0·4%C, 3%Si, and 8% Cr is described.—A. D. H.

Salt Bath Hardening of Tools. E. B. Hauser. (*Metal Progress*, 1955, **67**, Feb., 96–98). A short account of the use of this method of hardening by the Weldon Tool Co., U.S.A., of plain carbon, alloy carbon, and high-speed tool steels is given.—B. G. B.

On the Deterioration of Quenching Oils (II). M. Tagaya and I. Tamura. (*Tetsu to Hagane*, 1955, **41**, Jan., 32–41). [In Japanese]. Results are given in mathematical terms, which

allow quenching oils to be classified according to variations in quenching time, blowing time, viscosity, chemical composition, etc.—K. E. J.

FORGING, STAMPING, DRAWING, AND PRESSING

Hydraulic System for Press Operation. (*Brit. Eng.*, 1955, **37**, Apr., 359–360). A new hydraulic system for presses for compression moulding of plastics or rubber has been introduced by Finney Presses, Ltd. It is economical and flexible, meeting conditions where an intermittent pump demand is present; the operation depends on the Greer–Mercier hydropneumatic accumulator, enclosed in an alloy-steel shell. Three standard series are available, with max. working pressures of 1200, 3000, and 5000 lb./sq. in.—K. E. J.

Power Requirements and Flow Processes in Extrusion and Die-Forging. A. Geleji. (*Acta Techn.*, 1955, **10**, (1–2), 187–220). [In German]. The author's theory of extrusion (*Acta Techn.*, 1952, **7**, 273–283), previously tested on the works scale, is confirmed on the laboratory scale by tests on lead. The theory of die-forging is developed and experimentally confirmed.—P. F.

Comparative Examination of Different Systems of Hot Deformation. G. Dallapicola. (*Mét. Constr. Mécan.*, 1955, **87**, Feb., 129–133; Mar., 197–201). Hand forging, stamping into a mould, press stamping, and automatic forging are compared for the manufacture of small objects. Rolling, upsetting of parts heated by electric resistance methods, and forging and stamping of parts heated by high-frequency induction are also considered.—B. G. B.

New Metal Forming Processes. J. W. Gulliksen. (*Indust. Heating*, 1955, **22**, Feb., 298–304, 388–390). Developments in forging, extrusion, and deepdrawing are reviewed. The hydroform process of deepdrawing involving the use of a flexible die element is described.—A. D. H.

Tube Forging Lowers Fabricating Costs on Hollow, Shaped Parts. S. D. Johnson. (*Iron Age*, 1955, **175**, Feb. 3, 107–109). Modern achievements in hot tube forging are described. Steel tubing up to 24 in. dia. can be hot-worked by compression-forming into a variety of shapes such as long tapers, graduated diameters, and nosed, flared, flanged, upset, or expanded ends.—D. L. C. P.

The Chipless Forming of Rust- and Acid-Resisting Sheet. K. W. Michler. (*Maschinenwelt Elektrotechnik*, 1955, **10**, Feb., 42–44). The factors governing the drawing and pressing of ferritic and austenitic stainless steel sheet are outlined. L. D. H.

Stamping of Bomb Bases in Thick Sheet. B. Wassilieff. (*Mét. Constr. Mécan.*, 1955, **87**, 293–295).

Compressive Stress-Strain Properties of Thin Sheet Material. K. C. Rockey and F. Jenkins. (*Engineer*, 1955, **199**, Feb. 11, 190–191). A description is given of a testing rig which has been successfully used in obtaining the compressive properties of thin sheet material.—M. D. J. B.

Concerning the Question of Increasing the Speed of Hydraulic Presses. E. Nesnídal. (*Hutník*, (*Prague*), 1955, **5**, (2), 49–53). [In Czech]. Methods of attaining high speed in pressing and forging are considered in relation to the problem of the construction and conversion of equipment. The economic aspects are considered.—P. F.

Some Aspects of Drop Forging Practice. K. Fidler. (*Manchester Assoc. Eng. Preprints*, Feb. 18, 1955). An elementary account of the problems encountered and the equipment used in the drop forging of steel and light alloys is given. E. C. S.

How to Obtain Constant Wall Thickness on Drawn Cups. (*Iron Age*, 1955, **175**, Jan. 27, 86). The precautions necessary and the technique used to obtain a 7-in. dia. cup of uniform wall thickness 0·156 in. are described.—D. L. C. P.

Recent Investigations in Drawing and Entering of Steel Bars. Part I. W. Lueg and K. H. Treptow. (*Stahl u. Eisen*, 1955, **75**, Feb. 10, 162–169). Drawing and entering forces for bars of various steels were measured. Open-hearth steels St 00.12 and St 50.11 ($\frac{3}{4}$–$2\frac{3}{4}$ in. dia.) and die half-angles of 6°, 12°, 18°, and 24° were used. The forces for drawing and entering were measured for reductions of up to 20%. Lime and heavy engine oil were used as a lubricant. The results when drawing $\frac{3}{4}$-in. bars agreed fairly well with values calculated by the formulæ of Siebel, Körber, Eichinger, and Geleji. The entry forces are up to 55% higher than those for drawing.—T. G.

ROLLING-MILL PRACTICE

Study on the Hot Working Properties of Rimmed Steel (I). T. Ikeshima and T. Morishima. (*Tetsu to Hagane*, 1955, **41**, Jan., 17–22). [In Japanese]. Investigations were made with the object of reducing defects in tubes. Etching showed the presence of grey and black spots in the core of the billet, of which the latter acted as points of defect during hot working. K. E. J.

The Study of Rolling By Means of the Author's New Theory of Plasticity. M. Velasco de Pando. (*Dyna*, 1955, **30**, Jan., 9–18). [In Spanish]. The author has applied his theory of plasticity to rolling problems. A detailed mathematical treatment is given and equations, with which rolling stresses can be calculated, are derived.—P. S.

The Problem of the Static and Dynamic Loading of Reversing Two-High Plate Mills and Their Drive as the Basis for Suitable Design and for Drawing up Economic Rolling Programmes. O. Emicke. (*Met. u. Giesserei Techn.*, 1955, **5**, Jan., 19–34). The replacement of plain bearings by composition bearings, the use of twin-drive motors, and the installation of automatic control devices for standard rolling programmes are advocated.—L. J. L.

Determining the Static and Dynamic Load Factors of a Single Stand Plate Mill by Calculation and Test. K.-H. Lucas and O. Emicke. (*Met. u. Giesserei Techn.*, 1955, **5**, Jan., 7–19). Rolling pressure and deformation torque having been derived from tests, the deformation resistance factor K_s was compared with the results of seven different equations. These results differed widely; text data were, however, in good agreement with results of calculations on the Ekelund formula.—L. J. L.

On the Hydrodynamic Theory of the Rolling Process. G. Nickell. (*Met. u. Giesserei Techn.*, 1954, **4**, Nov., 484–487). The hydrodynamic theory formulated by A. Kneschke in opposition to Karman's static theory is shown to agree with experimental data. The theory offers an adequate quantitative and qualitative description of rolling processes. Suggestions are made for the practical application of Kneschke's formulæ.—L. J. L.

Power for Steel Rolling. Driving Equipment for an 11-in. Continuous Bar Mill. (*Elect. Rev.*, 1955, **156**, Jan. 28, 123–128). The layout and electric equipment of an 11-in. continuous bar mill installed at the Rotherham works of the Park Gate Iron and Steel Co., and put into operation in Sept., 1953, are described.—L. D. H.

How to Select Size of a Rolling Mill Drive Motor. A. J. Winchester. (*Blast Furn. Steel Plant*, 1955, **43**, Jan., 60–64). Two methods for the calculation of the size of motor for rolling-mill drives are explained.—B. G. B.

Magnetic Amplifier Proves Itself in Steel Mill Service. J. W. Brinks. (*Iron Steel Eng.*, 1955, **32**, Jan., 65). A brief description is given of Pittsburgh Steel Company's new 66-in., four-stand, 3190 ft./min., tandem mill which is equipped with 400-cycle magnetic amplifier regulators to control the voltage of the stand supply generators and the current and counter e.m.f. of the winding reel.—M. D. J. B.

The Practical Application of the "Eltas" Measuring Method at Hettstedt Rolling Mill. W. Feige. (*Met. u. Giesserei Techn.*, 1955, **5**, Jan., 34–37). The inductive method of measuring and recording rolling pressures, using differential bridge contacts, is described, and an example is given of its application in practice.—L. J. L.

Diagrams to Facilitate the Calculation of Roll Pressure, the Deformation and Bearing Friction Moments, Pending Stresses in the Roll Necks, and Mill Bearing Loads When Rolling Plates. O. Emicke. (*Met. u. Giesserei Techn.*, 1955, **5**, Feb., 44–50). Four nomograms are presented to enable even the theoretically untrained technologist to determine accurately and quickly the static and dynamic loads involved in rolling plates. These nomograms incorporate results calculated on the basis of Ekelund's formula and from the author's own tests.—L. J. L.

Application of Lubricants to Rolling Mills—Problems, Developments and Trends. W. G. Ritter. (*Iron Steel Eng.*, 1955, **31**, Dec., 78–83). The paper is limited to the study of centralized grease systems as used on cranes and rolling mills. The methods of pumping greases by electrically driven pumps, by hydraulic fluid, mechanical drives, and compressed air are discussed.—M. D. J. B.

Modern Techniques of Lubrication Applied to Old Mill Equipment. E. J. Weimer. (*Iron Steel Eng.*, 1955, **32**, Jan., 66–69). The author discusses the possibility of applying automatic lubrication to old mills and shows that although basic mill equipment may be obsolete, performance can be held at a competitive level through consistently adapting it to new developments.—M. D. J. B.

A New Blooming and Semi-Finishing Mill for Alloy Steels. E. Wiedemann. (*Stahl u. Eisen*, 1955, **75**, Jan. 27, 75–84). The author describes in detail the new blooming and bar mill of the Bochumer Verein. The mill consists of a reversing single-stand, 2-high blooming mill and a reversing 3-stand 3-high bar mill. Six water-cooled mercury-arc rectifiers supply the drive motors. The blooming mill has twin-drive, the first in the world for such a heavy mill. The mill is planned for a monthly output of 60,000–70,000 tons.—T. G.

Modernization of Rod Mill at Steel Company of Canada. D. W. Mclean. (*Iron Steel Eng.*, 1955, **32**, Jan., 59–63). This paper describes the conversion of a 2-strand, 16-stand rod mill, built in 1913, to a 20-stand, 3-strand mill. Details of the mill, mill equipment, and flying shears are given.

M. D. J. B.

Phoenix Manufacturing Co. Installs Versatile Rolling Mill. (*Iron Steel Eng.*, 1955, **32**, Jan., 153–155). This article describes a mill designed to produce a wide range of standard and special shapes at high speed and at minimum costs for changing rolls. The mill is capable of rolling billets from $1\frac{1}{2} \times 1\frac{1}{2}$ in. to 8 × 8 in. as well as rerolling railway axles.

M. D. J. B.

Carpenter Steel Installs Multi-Purpose Hot Rolling Mill. (*Iron Steel Eng.*, 1955, **31**, Dec., 126–129). A description is given of the new rolling mill of the Carpenter Steel Co. to produce strip, rods, and bars on one combined mill layout. The mill will have a monthly output of 3500 tons.—M. D. J. B.

Increasing Rod Production by Conversion of a 2-Strand Rod Mill to 3-Strand Operation. C. H. Burden and W. E. Zelley. (*Iron Steel Eng.*, 1955, **31**, Dec., 55–65). This article describes the method adopted at the John A. Roebling's Iron Co. for increasing the capacity of their rod mill. The existing mill was modified to roll more bars simultaneously; the general layout, controls, switching and drives were altered and the cooling beds improved.—M. D. J. B.

Rolling of Special Steels. A. Vach. (*Hutník* (*Prague*), 1955, **5**, (1), 7–10). [In Czech]. Problems generally met in the rolling of alloy steels, particularly those finished as rods or sections, are discussed.—P. F.

Experience Gained in Cold Rolling and Finishing Wide Strip in Tandem Mills. V. Seul and J. Billigmann. (*Stahl u. Eisen*, 1955, **75**, Feb. 10, 144–162). The authors describe the first wide-strip mill built in Germany since 1945 at the works of Stahl u. Walzwerke Rasselstein/Andernach, and the experience gained after one year's operation. The mill consists of a 3-stand 4-high tandem mill for strip 39 in. wide and a 2-stand finishing train with a 4-high and a 2-high stand. The mill will eventually be enlarged to a 5-stand train. Detailed operational data for both trains, including surface quality and hardness obtained, are presented.—T. G.

Plastics Reduce Roll Maintenance in Tinplate Line. (*Iron Age*, 1955, **175**, Jan. 20, 90–91). The production of plastic-covered rolls and their use in various parts of a tinplate line are dealt with. The rolls are wrapped with laminated plastic, cured and finish-machined. Surface hardness can be controlled according to use. The plastic is acid-resistant and these rolls are claimed to be superior to rubber-covered rolls.

D. L. C. P.

Three Mills Produce Welded Tubing from 2 inch to 4 inch in Diameter. (*Blast Furn. Steel Plant*, 1955, **43**, Feb., 220–222, 225). An illustrated account is given of three electric-resistance-welded tubing plants at the Babcock and Wilcox Co., Alliance, Ohio. Each mill is contained in a separate building and uses hot-rolled mill edge strip.—B. G. B.

Seamless Tube Mill at Pueblo Now in Production. (*Blast Furn. Steel Plant*, 1953, **41**, Nov., 1298–1300). A short account of this new mill of the Colorado Fuel and Iron Corp., Pueblo, California, is given. Tubes between $2\frac{3}{8}$ and $9\frac{5}{8}$ in. dia. are produced. A 70-ft. gas-fired rotary furnace is used to heat the billets. The mill is expected to produce 150,000 tons of seamless tube per year.—B. G. B.

J & L Adds Facilities to Tube Department. (*Iron Steel Eng.*, 1955, **31**, Dec., 130–132). Brief details are given of the equipment at the works of Jones and Laughlin Steel Corp. for straightening, hardening and tempering, and cooling special steel seamless tubes for the oil industry.

M. D. J. B.

Modern Templer Mill Drive. (*Metallurgia*, 1955, **51**, Jan., 29–32). A description is given of a new skin-pass mill at the Whitehead Iron and Steel Co., Ltd., Newport, supplied by Davy and United Engineering Co., Ltd., with the whole of the electrical plant and control gear by the General Electric Co., Ltd.—B. G. B.

Electrical Development in 1954. J. H. Hooper. (*Blast Furn. Steel Plant*, 1955, **43**, Jan., 70–82; Feb., 217–219, 225). A review of electrical drives for new rolling mills which have been constructed or modernized during 1954 is presented. Metallic rectifiers using germanium crystals have been developed for industrial use and are most suitable for voltages of up to 70V., D.C. A new heavy-duty D.C. magnetic brake is described.—B. G. B.

Investigations of the Most Economic Operation of Direct Current Reversing Motors for Plate Rolling Mills. M. Gündel. (*Met. u. Giesserei Techn.*, 1955, **5**, Feb., 50–60). The results of calculations and tests to determine the actual loads on D.C. motors for reversing mills are presented. The author concludes that changes of speed during rolling are undesirable and advocates automatic control.—L. J. L.

Control and Regulation Systems for Motors of Reversing Plate Mills. Different Methods of Operation. M. Gündel. (*Met. u. Giesserei Techn.*, 1955, **5**, Feb., 67–68). Dynamic transformers (Ward-Leonard sets) and static transformers (thyratron ignition), and dynamic amplifiers (amplidyne) and magnetic amplifiers, are described and compared. Twin-drive motors are finally discussed.—L. J. L.

Continuous Strip Tension Control: Operation of G.E.C. Exciter Scheme. (*Iron Coal Trades Rev.*, 1955, **170**, Feb. 18, 377–378). Details are given of the strip-tension control employed in the 21-in. single-stand 4-high temper mill at the Newport works of Whitehead Iron and Steel Co., Ltd.

C. G. F.

Steel Strip Cold Rolling. (*Elect. Rev.*, 1953, **153**, Oct. 30, 981–984; Nov. 20, 1147–1154). The electrical equipment used in the pickling and cold rolling of steel strip at the Port Talbot works is described.—L. D. H.

MACHINERY FOR IRON AND STEEL PLANT

Water Processing at Fairless Works. H. S. Spitz. (*Iron Steel Eng.*, 1955, **32**, Jan., 70–77). A description is given of the water system at the U.S. Steel Corporation's Fairless Works which requires 230 million gallons daily. The plant described includes the pumping station, clear and drinking water systems, boiler make-up water, and the sheet and tin and blast-furnace wash treatment plant.—M. D. J. B.

The New Central Power Station at Terre Rouge. M. Steffes and P. Mosel. (*Rev. Tech. Luxembourg*, 1955, **47**, Jan.-Mar., 25–39). A detailed account is given of the design and construction of this new power station on the border between France and Luxemburg which provides electrical power for the Arbed plants.—B. G. B.

Automatic Furnace Charging. C. M. Marquardt. (*Eng. Min. J.*, 1955, **156**, Mar., 94–97). Details are given of the automatic feeding and proportioning system used by Pioche Manganese Co. for their electric ferromanganese furnaces. It is based on F-M conveyor-belt scales, and handles ore, nodules, coke, flux, and slag from separate bins.—K. E. J.

Choosing Ore Feeders for Beneficiation Plants. O. W. Walvoord. (*Min. Eng.*, 1955, **7**, Feb., 131–134). Design data are presented to enable the most appropriate feeding devices to be chosen for given ores or ore mixtures. The data concern chain and belt, trough, rotary, screw, and other feeders, pumps, throat openings, bin discharge openings, feeder hoppers, and feeder drives.—K. E. J.

A.C. Winder with Dynamic Braking and Speed Control. (*Engineer*, 1955, **199**, Feb. 11, 196–197). The article describes a new system of dynamic braking and speed control as offered to the recently commissioned A.C. winder at Avon Colliery in South Wales. The winder is operated by a 1100-h.p. slipring motor which, with its control gear, is designed to raise about 3 tons of coal per wind, 47 winds per hour, from a depth of 1575 ft.—M. D. J. B.

Unit Loading, Power Trucks, Cut Foundry Handling Cost. F. J. Lynch. (*Iron Age*, 1955, **175**, Jan. 20, 83–85). The comprehensive mechanization of materials handling

in a large foundry is described. Battery-powered trucks using skid-lift, pallet-fork, and trailer methods transport raw materials, cupola metal, patterns, and castings.—D. L. C. P.

Electrical Development in 1954: Some Steelworks Installations. (*Iron Steel*, 1955, **28**, Feb., 61–64). Details are given of some of the outstanding electrical plant and equipment supplied in 1954 to steelworks and metal-using plants by the British Thomson-Houston, English Electric, and General Electric Companies.—G. F.

Excessive Stocks of Supplies for Maintenance Purposes. H. Haniš. (*Hutnické Listy*, 1955, **10**, (1), 16–21). [In Czech]. The problem of the origin of the accumulation, prevention of accumulation, and planning of depletion of surplus maintenance stocks is analysed.—P. F.

Transportable Containers for Heavy Goods. H. Lindahl. (*Jernkontorets Ann.*, 1955, **139**, (1), 55–62). [In Swedish]. Details are given of the dimensions, uses and costs of 1–3-ton capacity containers made of corrugated steel plate.—G. G. K.

Electrical Power Distribution and Utilization at Lone Star Steel Co. R. G. Orthwein. (*Iron Steel Eng.*, 1955, **31**, Dec., 104–112). A detailed account is given of the electric-power system at the works of the Lone Star Steel Co. including information on power requirements and supply, voltage and distribution systems, and on the arrangement of the main mill motor room.—M. D. J. B.

LUBRICATION

Lubricant Testing on the Timken Testing Apparatus. F. Dieker. (*Maschinenwelt Elektrotechnik*, 1955, **10**, Mar., 72–74). A description is given of the construction of Timken lubricant tester and its applications, particularly to the testing of high-pressure lubricants.—L. D. H.

Demands Placed on Lubricants in Service. E. Pietsch. (*Technik*, 1955, **10**, Apr., 226–231). The author surveys factors affecting performance of lubricating oils, such as pressure and temperature, for both thick- and thin-film conditions of lubrication.—J. G. W.

Development of Research into Lubricants. A. Dierichs. (*Technik*, 1955, **10**, Apr., 221–225). Investigations at the Freiberg Research Institute for Organic and Carbon and Oil Chemistry are reviewed, particularly those relating to Buna oil.—J. G. W.

Friction between Unlubricated Metals: a Theoretical Analysis of the Junction Model. A. P. Green. (*Proc. Roy. Soc.*, 1955, **A, 228**, Feb. 22, 191–204). The theory that friction is due to the shearing of junctions formed by adhesion between minute surface asperities is elaborated to show how the stresses and deformations in the junctions can be determined. Plasticine models assisted the work on deformation. The effects of ductility and hardness, and high friction between outgassed surfaces *in vacuo* are discussed.
K. E. J.

Porous Metal Filters for Lubricating Oils. (*Sci. Lubrication*, 1955, **7**, Feb., 17–19). Details are given of sintered brass filters made by Bound Brook Bearings Ltd. with controlled uniform porosity. Six grades are available, of which the finest can filter down to 1μ and the coarsest particles of $> 100\ \mu$. Applications to lubrication on automotive and stationary Diesel engines, machine tools, aircraft fuel oil, etc., are outlined.—K. E. J.

Mechanical Lubrication of Rolling Mill Spindles. (*Sci. Lubrication*, 1955, **7**, Mar., 40–41). Brief details are given of a new system in operation for spindle couplings at several Belgian plants.—K. E. J.

Lubrication Practices at Alan Wood Steel Company. R. G. Leister. (*Iron Steel Eng.*, 1954, **31**, Nov., 138–142). Modern control of existing lubricating devices and methods of application are discussed. The events of oil-mist lubrication, automatic application of heavy-duty lubricant to gears by spray, the lubrication of conveyor chains, and blooming-mill screwdown screw and nut are reviewed. Composition bearings and scale-guard installations are also dealt with.
M. D. J. B.

WELDING AND FLAME-CUTTING

Argon-Welding. E. Witting. (*Elektrowärme-Techn.*, 1955, **6**, Feb., 30–34). Welding and equipment in which argon is used as protective atmosphere are discussed.—P. F.

Brazing and Soldering by Induction Heating. E. S. Goodridge. (*Indust. Heating*, 1955, **22**, Jan., 64–70, 224–226). The advantages of induction heating in brazing and soldering operations are described, together with several applications of the process.—A. D. H.

A German View of Brittle Welded Structures. E. Houdremont. (*Metal Progress*, 1955, **67**, Jan., 114–120, 200, 202). The causes of brittleness in steels are reviewed and the commercial means of manufacturing tough metal are described. The author considers that the annealing of weldments (even local annealing of joints) will ensure a safe performance of a correctly designed and fabricated structure.—B. G. B.

Weldability of a C–Mn Steel Related to Properties of the Heat-Affected Zone. C. L. M. Cottrell. (*Brit. Welding J.*, 1955, **2**, Feb., 75–80). The existence of the critical temperatures of 290° and 245° C. for steels welded with B.S. 1719 class 2 and class 6 electrodes, respectively, has been shown to apply to a commercial carbon–manganese steel (B.S. 968 (*a*)). The critical temperatures relate to end of transformation during continuous cooling; when transformation continues below the critical temperature cold cracking will occur in the weld heat-affected zone. Results of rapid dilatation tests showed that with normal weld cooling rates, varying the peak temperature from 1250° to 1340° C. has little effect on end-of-transformation temperature. The dead-load rupture stress of simulated weld heat-effected zones gives a direct indication of the liability to cold cracking when welded with different types of electrodes. End-of-transformation cooling-time curves give a direct indication of weldability.—U. E.

Spot Welding of Hardenable Steels. H. E. Dixon. (*Brit. Welding J.*, 1955, **2**, Mar., 121–131). The author gives a review of information published up to June 1954.—U. E.

Stress Distribution in Side Fillet Welded Plates. P. J. Palmer. (*Brit. Welding J.*, 1955, **2**, Feb., 55–60). The principles of the theory involved in the determination of the stress distribution in double-cover-strap butt-jointed plates with longitudinal fillet welds are outlined. The method is basically known as ' shear-lag ' method. An example is given and the results show the variation of longitudinal direct stress over both the main and the cover plates. A comparison is made with stresses determined experimentally on a similar specimen and the agreement is shown to be very good.—U. E.

Helium–Nitrogen Shielding Gas Improves Welding of Low-Carbon Steel. E. L. Turner and W. F. Heller. (*General Motors Eng. J.*, 1954, **1**, July-Aug., 9–11). Comparison tests of butt and fillet welds produced in helium–nitrogen and helium–argon shielding gas mixtures are described. The mechanical properties of the helium–nitrogen welds are comparable or slightly better than those of the helium–argon welds, and when welding the former, the authors noted reductions in gas consumption, current consumption and the quantity of filler used. A smaller, cleaner bead was produced in helium–nitrogen welds.—J. E. J.

The Manufacture of Steel Chain Cable. (*Machinery*, 1954, **85**, Oct. 3, 1189–1192). Special methods used by Newman Industries Ltd., Yate, Bristol, in the manufacture of steel-link type steel chain cable are described. The technique, known as the Unionmelt electric fusion weld process, is employed for steel bar $1\frac{1}{4}$–$2\frac{3}{4}$ in. dia. Both mild and high-tensile steel chain are made by the same method.—M. A. K.

Hydrogen—Welding's Big Troublemaker. H. Thielsch. (*Steel*, 1954, **135**, Sept. 27, 84–85; Oct. 4, 108–111, 118). The role of hydrogen in causing weld defects is explained, and practical means of minimizing these are given. A chart specifies suitable electrodes and preheating and stress relieving procedures for various A.S.T.M. steels; drying treatments for the electrodes are also recommended.
D. L. C. P.

The Special Characteristics of Acetylene as a Combustible Gas for Oxygen Cutting. (*Rev. Soudure*, 1954, **10**, (4), 199–203).

MACHINING AND MACHINABILITY

A Machine for the Measurement of Rolling Friction. J. Halling. (*J. Sci. Instruments*, 1955, **32**, Jan., 8–9).

Surface Finish, Dimensional Accuracy and Alteration in Structure of Workpieces Machined by Electric Methods. H. Opitz. (*Microtecnic*, 1955, **9**, (1), 14–20). The techniques of machining by means of electro-erosion are described and compared, and the results obtained are discussed.—L. D. H.

The "Sigmatrol" Machine Controller. (*Microtecnic*, 1955, **9**, (1), 46–47). A brief description is given by the makers of a new two-stage machine controller, which automatically stops the infeed of a machine when a correct dimension is reached.—L. D. H.

A New Instrument for Measuring Surface Roughness. M. Pesante. (*Microtecnic*, 1955, **9**, (1), 27–31). An instrument is described which represents an advance on the profilometer. In addition to the average roughness, R_a, and the r.m.s. roughness R_s, as measured in the profilometer, the instrument can also be used to determine the average roughness height R_p, total height R_t, average roughness depth $R_m = R_t - R_p$ and the form factors $K = R_p/R_t$ and $K' = R_m/R_t$. The instrument is built as a number of units, and if desired can be adapted as an extension of existing profilometers.—L. D. H.

Friction Apparatus for Very Low-Speed Sliding Studies. F. Heymann, E. Rabinowicz, and B. G. Rightmire. (*Rev. Sci. Instruments*, 1955, **26**, Jan., 56–58). A problem in studying 'stick–slip' (relaxation oscillations) in low-speed frictional measurements is to prevent stick–slip between the surfaces of the driving mechanism. This is largely obviated in the method described by the use of a weight, the speed of which is controlled by the viscous drag of a paddle in a pitch bath. Precautions are also described to reduce stick–slip in the measuring device. Speeds of the order of 10^{-7}–10^{-4} cm./sec. are used.—L. D. H.

Apparatus for Studying Friction and Sliding Electrical Contacts. D. G. Flom. (*Rev. Sci. Instruments*, 1955, **26**, Jan., 1–4). An apparatus is described for frictional and sliding electrical contact studies, under precise atmospheric control. The sliding contact consists of a rider (or brush) bearing against a magnetically driven rotating cylinder. Movement of the rider caused by frictional force is measured by wire resistance strain gauges or, in the case of large increments of wear, by a dial wear indicator.—L. D. H.

High Power Spark Erosion Machine. L. R. Blake. (*Engineer*, 1955, **199**, Feb. 18, 222–226). Most spark erosion machines commercially suitable employ the resistance charged capacitance relaxation circuit, with servo control of the cutting electrode. This circuit has an inherently low electrical charging efficiency, which virtually restricts its use to low cutting powers. This disadvantage has been overcome by charging the capacitor through an inductor which is also used as a vibrator of the cutting electrode to ensure repeated and reliable discharge of the capacitor at peak electrical energy. By counterbalancing the vibrator head and allowing the cutting electrode to advance under gravity, it has been possible to eliminate the expensive servo control.—M. D. J. B.

Automatic Billet Grinder Triples Production. W. K. Lowe. (*Iron Age*, 1955, **175**, Jan. 13, 86–87). A new automatic billet grinder developed by Crucible Steel Co. for full surface or spot grinding alloy steel billets up to 5 in. square is described.—D. L. C. P.

Machining by High Frequency Vibration Techniques. E. A. Neppiras. (*Research*, 1955, **8**, Jan., 29—34). Very hard materials, such as die steels and sintered carbides, may be shaped by the action of abrasive powders suspended in liquid and subjected to ultrasonic vibrations. The method provides rapid cutting rates, extreme accuracy, and good finishes without heating the work.—K. E. J.

Design Considerations Applying to Specification of Surface Finish for Machined Parts. J. F. Hagen and E. E. Lindberg. (*General Motors Eng. J.*, 1954, **1**, July-Aug., 12–17). The development of a standard method of indicating on engineering drawings the degree of surface finish required for machined parts is described.—J. E. J.

A Discussion of Instrumentation for Determining Surface Roughness of Machined Parts. J. F. Hagen and E. E. Lindberg. (*General Motors Eng. J.*, 1954, **1**, July-Aug., 18–23). A brief description is given of interference-microscope, translucent-replica, and taper-sectioning methods of measuring surface roughness. The more recently developed tracer-type instruments are described and discussed in detail.—J. E. J.

Some Aspects of Spark Machining. M. G. Seed and H. Drubba. (*Engineers Digest*, 1954, **15**, Sept., 378–380). Problems involving the machining of very hard materials such as carbides has been solved by the introduction of 'spark machining.' This is based on the erosive action of a rapid succession of spark discharges between electrodes, one being the tool and the other the workpiece itself. Erosive action is greatly intensified by submerging both tool and workpiece in a suitable non-conductive liquid.—M. A. K.

The Application of CeDeCut Cooling to a Boring Operation. (*Machinery*, 1954, **85**, Dec. 10, 1250–1252). The article describes the results obtained with the CeDeCut liquid CO_2 cooling technique recently applied to a difficult boring operation at Clarke-Built Ltd. It is claimed that speed and feed were substantially increased and tool life was improved.
M. A. K.

CLEANING AND PICKLING

Notes on the Use of Sand and Steel Shot. (*Mét. Constr. Mécan.*, 1955, **87**, Mar., 205–206).

Pre-Treatment of Steel. (*Corrosion Techn.*, 1955, **2**, Feb., 55–56). The methods of removing scales (mill and rust), moisture, grease, and chemical deposits are briefly described.
L. E. W.

Adhesion and Surface Preparation in Protective Metal Spraying. (Part III). J. M. Cowan. (*Electroplating*, 1955, **8**, Feb., 67–72). The construction of blasting chambers and details of the Vacu-Blast system which can be used without any chamber are given. Centrifugal-type machines are described and compared with compressed-air systems. Automatic equipment is briefly discussed.—A. D. H.

Small Foundries Can Afford Better Cleaning Departments. E. F. Anderson. (*Foundry*, 1955, **83**, Feb., 82–83, 246, 248–249). The importance of an efficient cleaning department in small foundries is stressed and suitable types of automatic blast-cleaning equipment are discussed.—B. C. W.

Incentive Plan in the Cleaning Room. R. V. Shaffer. (*Foundry*, 1955, **83**, Feb., 168, 170, 172).

Steam Oxidizing Provides Better Paint Base. L. E. Raymond. (*Iron Age*, 1955, **175**, Jan. 13, 75–77). The use of dry steam treatment for preparing the surfaces of steel or cast iron parts for painting is described. Cost may be 75% of that for chemical treatment, and no entrapped chemicals can cause trouble from bleeding after painting. Clean parts are loaded into a pressure furnace and treated with steam; steel parts require about 1 hr. at 750° F., cast iron parts 1200° F. for somewhat longer.—D. L. C. P.

Cold Cleaners Do Effective Job in Still and Spray Tanks. J. McElgin. (*Iron Age*, 1955, **175**, Feb. 3, 110–112). Examples of applications and advantages of cold solution cleaners are given. Specifically discussed are "Houghto-Clean Nos. 402 and 403," which may replace petroleum solvents and hot alkaline cleaners for removing shop oil and dirt.—D. L. C. P.

Chemical or Mechanical Descaling of Steel Bars? O. Peltzer. (*Stahl u. Eisen*, 1955, **75**, Feb. 10, 129–140). As legislation in Germany on pickling waste disposal may soon cause costs to rise, the author discusses the various mechanical descaling methods and German and Swiss machines available at present. He concludes with a detailed cost calculation and finds that chemical descaling will be more than twice as expensive as blast cleaning.—T. G.

Acid-Free Chemical Method of Descaling Stainless and Heat-Resisting Steels. B. Wenderott. (*Stahl u. Eisen*, 1955, **75**, Feb. 10, 141–144). High-alloy, stainless, and heat-resisting Cr–Ni steels on the basis can satisfactorily be descaled in a mixture of molten NaOH and $NaNO_3$. The steel is subsequently freed from salt residues and annealed in a reducing atmosphere. The surface quality is said to be equal or better than that after ordinary pickling. Cold working is facilitated by a surface layer of iron or iron–nickel (the chromium in the surface layer is dissolved by the salt mixture). The converted surface layer of sheet material does not need to be removed for cladding. The process has been applied in wire production.—T. G.

Hot Oxidation of Iron. V. Montoro. (*Met. Ital.*, 1954, **46**, Nov., 410–412). The author studies the oxidation of iron with temperature, in relation to chemical composition and to adherence and compactness of the oxide film formed. The diagram of oxidation rates suggests two different behaviours for temperatures below and above 500° C. Points on the diagram which differ from the normal trend at 530° and 860° C. can be attributed to oxygen gas penetrating through holes and cracks in the oxide film. The return to normal behaviour at temperatures around 700° and 1000° C. is attributed to non-permeability of the Fe_2O_3 layer.
M. D. J. B.

Economical Pickling in Theory and Practice. A. Pollack. (*Metalloberfläche*, 1955, **9**, Feb., A17–A22). Economies in

pickling, effected mainly by the use of inhibitors, acceleration of the process by means of activators, economy of material by pickling at elevated temperatures, recovery of the acid, and utilization of the iron sulphate are described.—L. D. H.

Cleaning of Castings. L. B. Childe. (*Foundry Trade J.*, 1955, **98**, Jan. 27, 87–97). A detailed review is given of the cleaning of castings by abrasive blasting and centrifugal shotting. The review includes plant design, properties of abrasives, construction of hoses and nozzles dust-extraction equipment, and legal requirements.—B. C. W.

Ten Years of Mechanical Descaling of Hot Rolled Steel Products. G. D. Dill. (*Iron Steel Eng.*, 1955, **32**, Jan., 85–89). The author describes slab and billet descaling and sheet and continuous strip descaling by high-capacity shot-blasting equipment.—M. D. J. B.

How Abrasive-belt Grinding Improves Taper Sheet Production. J. R. Burns. (*Machinist*, 1955, **99**, Jan. 7, 28–30). Tapered sheets, a recent innovation for aircraft efficiency, have been produced from aluminium and stainless steel for wing and fuselage skins. The article describes the abrasive-belt grinding and polishing machine designed and built by Bell Hill-Acme Co. of Cleveland, Ohio, and the methods used.—M. A. K.

PROTECTIVE COATINGS

The Plating of Screw Threads. A. W. Wallbank. (*Trans. Inst. Met. Finishing*, 1955, **32**, Advance Copy No. 10).

Electrolytic Oxidation of Copper and Copper Alloys in Hot Alkaline Solution. S. G. Clarke and J. F. Andrew. (*Trans. Inst. Met. Finishing*, 1955, **32**, Advance Copy No. 8).

Structure and Growth of Electrodeposits and the Modifications Caused by Brightening Agents. H. Wilman. (*Trans. Inst. Met. Finishing*, 1955, **32**, Advance Copy No. 9).

Determination of Plating Quality. G. Howells. (*Corrosion Techn.*, 1955, **2**, Jan., 9–12). The author outlines methods of testing for plating quality with particular reference to adhesion, porosity, hardness, lustre, and identity of plating. L. E. W.

CHC—A New Vapour Phase Inhibitor. (*Corrosion Techn.*, 1955, **2**, Jan., 8). The physical, chemical, and inhibiting properties of CHC (cyclo-hexylamine carbonate) are briefly described. A high degree of protection is given by the CHC vapour to mild steel, cast iron, aluminium, chromium-plated steel, tinplate, zinc, and solder.—L. E. W.

Technical Developments of 1954. N. Hall. (*Metal Finishing*, 1955, **53**, Jan., 58–66). A comprehensive review is made of published work and patents dealing with the cleaning, polishing, pickling, coating, and testing of metals. (285 references).—A. D. H.

Plating Wastes—A Review of Research. D. G. Foulke and R. F. Ledford. (*Metal Finishing*, 1955, **53**, Jan., 67–75). Fundamental and development research on effluent treatment and disposal are reviewed. (63 references).—A. D. H.

Rinsing Techniques. J. B. Kushner. (*Metal Finishing*, 1955, **53**, Jan., 76–79). The theory and practice of removal of solids and salts during metal finishing processes is discussed. A. D. H.

Influence of Product Design for Electroplating. F. C. Ashford. (*Electroplating*, 1955, **8**, Feb., 50–53). Basic principles of design are stated allowing efficient economic plating processes to be carried out. Several examples of ideal and faulty design are quoted.—A. D. H.

Throwing Power of Complex Copper Electrolytes. A. V. Izmaylov and S. V. Gorbachev. (*J. Phys. Chem. U.S.S.R.*, 1954, **28**, 229–239; *Electroplating*, 1955, **8**, Feb., 54–57, Mar., 99–100). It is shown that in electrolytes containing $CuSO_4$ the addition of mono– or triethanolamine first increase the throwing power to a maximum, after which it then decreases. The addition of up to 0·6 mols/l. of $Na_2P_2O_7$ also increased throwing power but here the increase in temperature had little effect. The dependence of throwing power on activation energy is discussed.—A. D. H.

Periodic Reverse Current Electroplating. A. Whittaker. (*Machinery*, 1955, **86**, Feb. 25, 416–420). This process involves the reversal of polarity of the work to be electroplated, for controlled periods, which produces bright surface levelling deposits at high speeds, and enables the amount of mechanical finishing to be reduced.—M. A. K.

Peroxygen Compounds Hold Important Place in Treating Metal Surfaces. P. H. Margulies. (*Iron Age*, 1955, **175**, Jan. 27, 71–74). Examples are given of the use of hydrogen peroxide solutions, persulphates, and peracids for protection or cleaning of metal surfaces, and regulating the state of oxidation of certain treating solutions.—D. L. C. P.

Modern Electroplating. A. G. Gray [editor]. (Electrochemical Society: John Wiley & Sons, Inc., New York, and Chapman & Hall, Ltd., London, 1953, 563 pp.). The Electrodeposition Division of the Electrochemical Society held a symposium on electroplating during its 80th meeting at Chicago in 1941. When the subject of revision arose, it appeared desirable to prepare an entirely new book, and this volume, also sponsored by the Electrochemical Society, is the result. The contributions are by 39 experts, each actively engaged in his, or her, particular field. It comprises the following papers:

General Principles. W. Blum and W. R. Meyer. (1–46).
Methods of Control. R. A. Schaefer, H. J. Sedusky, and Betty Luce. (47–63).
Alloy Plating. C. L. Faust. (64–97).
Brass. L. E. Weeg and H. J. Wiesner. (98–115).
Cadmium. K. G. Soderberg and L. R. Westbrook. (116–134).
The Chromium Plating Process. G. Dubpernell. (135–177).
Properties of Chromium Plate. C. A. Snavely and C. L. Faust. (177–187).
Cobalt. H. B. Linford. (188–193).
Rochelle Copper. A. K. Graham and H. J. Read. (194–213).
High Efficiency Cyanide Copper. R. R. Bair and D. A. Swalheim. (213–225).
Pyrophosphate Copper. J. E. Starek. (225–231).
Acid Copper Electroplating and Electroforming. W. H. Safranek and J. H. Winkler. (231–251).
Gold. L. Weisberg and A. K. Graham. (252–266).
Indium. H. B. Linford. (267–270).
Iron. C. T. Thomas and V. A. Lamb. (271–281).
Lead. A. H. du Rose and W. Blum. (282–298).
Nickel. W. L. Pinner, K. G. Soderberg, and W. A. Wesley. (299–355).
Platinum Group Metals. K. Schumpelt. (356–366).
Silver. N. E. Promisel. (367–386).
Stannate Tin. F. Bauch and F. F. Oplinger. (389–410).
Acid Tin. P. R. Pine and A. H. du Rose. (410–428).
Immersion Tinning. F. A. Lowenheim. (429–434).
Tin Alloys. F. A. Lowenheim. (434–442).
Acid Zinc. E. H. Lyons, jun., and H. P. Munger. (444–459).
Cyanide Zinc. R. R. Bair and L. J. Schustik. (460–482).
Uncommon Metals. F. A. Lowenheim. (483–510).
Plating on Aluminium and Magnesium—Aluminium Alloys. F. Keller. (511–524).
Plating on Aluminium and Magnesium—Magnesium Alloys. H. K. DeLong. (524–535).

Comparative Investigations on Methods of Measurement of Layer Thicknesses. H. Barghoorn. (*Metalloberfläche*, 1955, **7**, Jan., B8–B11; Feb., B20–B25; Mar., B36–B38). Various methods of measuring the thicknesses of metal layers are compared, and their probable errors estimated.—L. D. H.

Investigations in Surfaces with Exo- and Photoelectrons. J. Kramer. (*Metalloberfläche*, 1955, **9**, Jan., A1–A6; Feb., A28–A31). The nature and properties of electrons produced thermally and photoelectrically are outlined, and apparatus is described, and applications discussed for use in the investigation of metallic surfaces by the production of exo-electrons.—L. D. H.

Hardness and Wear Resistance of Electrolytic Metal Coatings. R. Weiner and G. Klein. (*Metalloberfläche*, 1955, **7**, Jan., B1–B7). The micro-indentation hardness, scratch hardness, and abrasion losses were determined on a large number of electrolytically coated surfaces. It was shown that there was, in general, no close relationship between these three quantities, but that in general a lower resistance to abrasions tended to be associated with a decrease in scratch hardness relative to micro-indentation hardness. Comparative tests between coatings from bright-plating and ordinary baths showed that the scratch hardness of the former could be appreciably less than that of the latter even though their micro-hardness was greater.—L. D. H.

New Dutch Factory for Porus-Krome Process. (*Sci. Lubrication*, 1955, **7**, Feb., 20–21). An account is given of a new works operating the process for producing hard but porous electrodeposited chromium linings on cylinder walls and liners. Channel-type pores are used in aircraft piston engines, and pocket type pores in Diesel engines, compressors, etc. Lubricating oil consumption is reduced by 30%, and the process can be used for worn parts by first building up with electrolytic iron (Vanderloy process).—K. E. J.

Hot Dip Galvanizing—Temperature Control Key to Longer Pot Life. W. G. Imhoff. (*Iron Age*, 1955, **175**, Jan. 20, 92–94). An investigation is reported into the effect on iron of molten zinc at various temperatures. Above 900° F. the dissolving action of zinc increases rapidly. It is recommended that maximum operating temperature for hot-dip galvanizing pots should be 885° F., and the heat should be applied uniformly to the sides of the pot.—D. L. C. P.

Study of Ridges on Hot Dipped Tin Plate. S. Chatel, P. Kozakevitch, and P. Rocquet. (*Métaux-Corrosion-Indust.*, 1955, **30**, Feb., 78–87). Examples are given of the formation of ridges on the surface of hot dipped tinplate. The exact profile of the ridge has been measured by interferometry and a mathematical representation of their shape is developed. The mechanism of ridge formation is discussed and methods used to suppress it are described.—B. G. B.

Some Recent Advances in Tinplate Manufacturing Processes. W. E. Hoare. (Tin Research Inst., Jan., 1955). Steel base composition and the influence of hot-mill conditions on final steel base structure are discussed. Continuous strand annealing is described and illustrated, and the three general types of electrolytic tinplate line and a modern hot-dip tinning line are also described, with a note on manufacturing control tests. The mechanical properties of tinplate, the present status of electrolytic tinplate installations and coating weights, and approximate yield figures for electrolytic and for hot-dipped canning grades are shown in tables. Graphs of world production of tinplate for 1942–52 inclusive are given.—E. C. S.

Hot Dipped Aluminium Coatings. (*Corrosion Techn.*, 1955, **2**, Mar., 90–91). The properties, applications, and economics of this form of coating are briefly surveyed and reference is made to the experimental work that has been carried out in the U.K.—L. E. W.

Cyanide Copper Baths, in Particular High Output Baths. H. W. Dettner. (*Metalloberfläche*, 1955, **7**, Mar., B33–B35). An outline is given of the development and applications of copper plating from cyanide baths. High output baths, with and without additions of Rochelle salt, are described in greater detail.—L. D. H.

A Survey of Chromate Treatments. W. E. Pocock. (*Metal Finishing*, 1954, **52**, Dec., 48–51; 1955, **53**, Jan., 80–83). Theory, methods, and applications of chromate treatments for non-ferrous and cadmium and zinc-coated materials are reviewed.—A. D. H.

The Present Position of Phosphating Processes for Iron and Non-Ferrous Metals. W. Machu. (*Werkstoffe Korrosion*, 1955, **6**, Feb., 72–80).

Complete Finishing System Installed on Roof at Hamilton Mfg. Co. (*Indust. Heating*, 1955, **22**, Feb., 355–368). A large conveyor-system for phosphating and painting large and small steel components is described in detail.—A. D. H.

The Phosphatization of Ferrous Metals. J. Valsell Viver. (*Dyna*, 1955, **30**, Jan., 56–58). [In Spanish]. The problem of corrosion is discussed and the value of phosphate coatings is described. The development of the phosphating process, its limitations in relationship to the composition of the steel, its advantages and disadvantages as a protective coat, methods of producing phosphated surfaces, and the industrial applications of the process are reviewed.—P. S.

Combating Corrosion in the Potteries. (*Ceramics*, 1955, **6**, Jan., 506–507). The 'Jenolizing' process has been applied to metalwork in the factory of a tile manufacturer in the Potteries and found to assist in corrosion prevention. It entails the simultaneous removal of rust and the deposition on the metallic surface of a phosphate coating which inhibits corrosion and keys the surface for paint adhesion.—D. L. C. P.

Flame Spraying of Non-Metallic Protective Layers on Metal Surfaces. H. Reininger. (*Metalloberfläche*, 1955, **9**, Jan., A6–A9). The author outlines methods reported in the literature for the flame spraying of plastics and other non-metallic substances on to metal surfaces.—L. D. H.

The Blistering of Paint Films on Steel Surfaces. A, Nicholson and H. A. H. Jenkins. (*Trans. Inst. Met. Finishing*. 1955, **32**, Advance Copy No. 13).

Design for Gas Heated Plant for Stoving by Radiant Heat (Infra Red). A. E. Tyrrell. (*Electroplating*, 1955, **8**, Feb., 58–64). Examples are given of two types of installation for paint drying. One employs medium temperature black emitter panels (450–650° F.), the other, which operates between 600° and 1000° C. uses incandescent sources.—A. D. H.

POWDER METALLURGY

Sintered Machine Parts. G. Zapf. (*Z. V. d. I.*, 1955, **97**, Feb. 1, 89–96). Powder metallurgy as applied to the manufacture of machine elements, is surveyed. New developments, such as the addition of copper to iron, heat-treatment to improve mechanical properties of product, and repeated pressing and sintering to improve dimensional precision, are referred to.—J. G. W.

Measurement of the Complex Permeability of Carbonyl Iron Powders at 4000 Mc/s. A. Nishioka and H. Okamoto. (*J. Phys. Soc. Japan*, 1955, **10**, Jan., 79). The effect of particle size on permeability of polyiron for microwave attenuators was investigated for the range 5–20μ. A pronounced skin effect was present in all powders.—J. G. W.

Furnaces and Furnace Atmospheres for Sintering Operations. C. G. Paulson. (*Indust. Heating*, 1955, **22**, Feb., 276–280). Reactions between oxygen, hydrogen, and carbon which occur during sintering processes are explained. Pusher-type atmosphere furnaces are described.—A. D. A.

Progress in Powder Metallurgy. H. W. Greenwood. (*Metallurgia*, 1955, **51**, Jan., 33–35). A review of recent advances in powder metallurgy is presented. The impregnation of porous bearings with materials having a low coefficient of friction is finding increasing use. The production of metal in sheet form by flame spraying and the use of metal powders in flame cutting are also described.—B. G. B.

How to Produce Hard Tough Steel Parts from Powder Metal. J. W. Young. (*Iron Age*, 1955, **175**, Feb. 3, 119–122). Examples are given of how small, close-tolerance, highly stressed steel parts can be made to advantage by modern powder-metallurgy techniques. Density ratios above 98% are attained.—D. L. C. P.

PROPERTIES AND TESTS

The Ultimate Strength of Thick Walled Cylinders Subjected to Internal Pressure. I. Apparatus for Producing Very High Pressures. II. Test Results and Their Relation to Ultimate Strength Equations. B. Crossland and J. A. Bones. (*Engineering*, 1955, **179**, Jan. 21, 80–83; Jan. 28, 114–117). This article describes tests carried out to provide the accurate experimental evidence required to establish the validity of formulæ for assessing the ultimate strength of thick-walled cylinders subjected to internal pressure. It gives the authors' conclusions on these formulæ, and describes an apparatus developed for producing pressures up to 46 tons/sq. in.

M. D. J. B.

Structural Anisotropy, Mechanical Behaviour, and Standardization of Grey Iron Castings. A. Collaud. (*Giesserei Technisch-Wissenschaftliche Beihefte*, 1954, Dec., (14), 709–726). Distinction is made between the pure chemical analysis of a grey iron casting and the chemical-physical composition. Anisotropy and the influence of wall thickness are discussed. A description of the peculiarities of the structure and their influence on the mechanical behaviour of grey castings is followed by a discussion on internal stresses and their removal. The application of Hooke's law to grey casting leads to a discussion on the modulus of elasticity, bending experiments, and the primary structure.—R. J. W.

Stress Measurements in Cast Iron by the Invariant Method. H. Schlechtweg. (*Giesserei Technisch-Wissenschaftliche Beihefte*, 1954, Dec., (14), 727–729). This theoretical paper describes the so-called 'invariant' method of stress analysis which may be used in place of the older sum-and-difference method. This method simplifies the calculation, but to determine the stresses at any one point on the surface, the stress normal to the surface at that point must be known.

R. J. W.

Production of Specimens for Static and Fatigue Testing. T. S. Braithwaite. (*Machinery*, 1955, **86**, Jan. 7, 34–36). Special machining and polishing methods have been developed

in the Central Workshop of the Mechanical Engineering Research Laboratory for making specimens for static and fatigue testing to ensure accuracy and high finish. There are general machining restrictions in force to avoid setting up stresses in specimens.—M. A. K.

Wire Strain-Gauge Transducers for the Measurement of Pressure, Force, Displacement, and Acceleration. J. L. Thompson. (*J. Brit. Inst. Radio Eng.*, 1954, **14**, Dec., 583–601). The theory, design, and applications of resistance wire strain gauges for the measurement of pressure, vibration, acceleration, force, and torque are discussed. The construction and use of unbonded strain gauges are described, and the paper concludes with practical details of the use and adjustment of these instruments.—L. D. H.

Effects of Surface Treatment on the Strength and Endurance of Steels. (*Eng. Digest*, 1954, **15**, Nov., 466–468). In this summary of six papers in *Vestnik Mashinoestroyna* the effect of directional strain hardening on the strength and fatigue strength of steels is discussed. Experiments carried out to determine the effect of H.F. induction hardening on the endurance limit of 0·5% C steel and the effect of shot-peening on the endurance strength of steel under repeated impact are described. Tests to determine the effect of heat-treatment and hot-working on the endurance strength of austenitic steels and the optimum cutting speeds for the finish-machining of various steels are described.—J. E. J.

Fallacies and Paradoxa in the Plasticity Theory. H. Craemer. (*Acta Techn.*, 1955, **10**, (1–2), 73–82). **Comments of Prof. H. Craemer's Paper: "Fallacies and Paradoxa in the Plasticity Theory."** I. Sályi. (*Acta Techn.*, 1955, **10**, (1–2), 83–89). It is shown that some assumptions frequently made in the theory of plasticity in dealing with the behaviour of structure at and before failure are inconsistent with the assumed stress–strain law, thus leading to paradoxical results. A number of specific cases of the deflection of beams and the mode of onset of plasticity are used as illustrations. Sályi points out that Craemer's considerations are invalid for large deformations.—P. F.

Apparatus for Measuring the Elastic Moduli and Internal Friction of Solids from 1·7 to above 77° K and some Values for α-Quartz. M. E. Fine. (*Rev. Sci. Instruments*, 1954, **25**, Dec., 1188–1190).

Three-dimensional Photo-elasticity in the Construction of High-Pressure Apparatus. C. Alt. (*Z. V. d. I.*, 1955, **97**, Feb. 11, 127–170). The application of three-dimensional photo-elasticity to the design of components of high-pressure equipment is illustrated by several examples including valve bodies. The photo-elastic technique, notably the choice of suitable plastics, is also discussed.—J. G. W.

The Significance of an Electron Bombardment for the Plasticity of Metal Crystals. E. Schmid and K. Lintner. (*Z. Metallkunde*, 1955, **46**, Feb., 71–76). The Seitz and Brinkman theories of the effects of corpuscular radiation on solids are outlined and the experimental evidence on the influence of bombarbment with α and β particles and electrons on deformability of metal crystals is surveyed.—L. D. H.

An Effective Method of Gripping Short Specimens of Wire Strand for Tensile Tests. F. D. Hills. (*J. Sci. Instruments*, 1955, **32**, Jan., 33–34). The strands of the wire to be tested are set into a truncated cone of quick-setting Marco resin; by this means the inner wires are held firmly, and no crushing of the outer wires takes place.—L. D. H.

Combined Tension and Torsion Machine for Relaxation Tests. A. E. Johnson and N. E. Frost. (*Engineer*, 1954, **198**, Dec., 17, 834–835). The article describes a machine for carrying out complex stress-relaxation tests at high temperature. The tests can be conducted under combinations of tension bands up to 600 lb. and torques up to 1000 in. lb. over a temperature range of 20–800° C.—M. D. J. B.

Comparison of some Hardenability Tests in the Case of some Steels of Low Hardenability. F. Labonek. (*Hutnické Listy*, 1955, **10**, (3), 162–168). [In Czech]. The Jominy, Shepherd, and fracture tests of determining hardenability were applied to three types of frequently used carbon tool steels, and the results were compared. The common fracture test, which also permits grain-size evaluations and an assessment of the liability to burning, was found most appropriate.—P. F.

Roof Conditions in a V-notch Charpy Impact Specimen. H. A. Lequear and J. D. Lubahn. (*Welding J.*, 1954, **33**, Dec., 585s–588s). The maximum conventional strain (in percent.) at the root of a **V**-notch Charpy impact specimen has been found to be about 10 times the angular displacement (in degrees) between the two ends of the bent specimen. The specimens consisted of a 5-in. round brass bar, 4-in. hot-rolled mild steel plate, and a 4-in. square hot-forged 28 aluminium bar. The biaxiality at the notch bottom rises rapidly from zero at the side faces and reaches 0·48 at the mid-width in all three specimens. Average strain at the notch bottom measured over a gauge length equal to the root radius is within 10% of the maximum.—U. E.

Comparison of the Slow Notch-Bend Test and the V-notch Charpy Impact Test. (*Brit. Welding J.*, 1955, **2**, Mar., 98–106). The slow notch bend test and **V**-notch Charpy impact test were employed for the assessment of the notch ductility of 1-in. wide carbon-manganese steel plate. Experimental results are given in tables. The two tests give a similar rating but in the case of one steel the difference between the tests alter its rating to a significant extent. Where fracture appearance is to be considered, the slow bend test is to be preferred to the **V**-notch Charpy test. The two types of criteria measuring the resistance to unification of cleavage failure from a notch or from a travelling fibrous crack respectively give the same general rating to the steels tested but there are significant differences which may be of importance.—U. E.

Nonuniform Stress Distribution in Dynamic Loading. E. Siebel and M. Stieler. (*Z. V. d. I.*, 1955, **97**, Feb. 11, 121–126). The attenuating effect of stress gradient on notch sensitivity in dynamic loading was investigated experimentally in Amsler and Schenck bending fatigue testing machines. Sixteen materials were employed, including seven wrought steels and a cast steel. It was concluded from the experiments, results of which are quoted fully, that the apparent strengthening in fatigue for a given configuration depends on the stress gradient. In addition the presence of a size effect was established, and it is suggested that this could be expressed in terms of a ratio of notch size to a representative dimension of material structure, e.g. mean grain diameter.—J. G. W.

Residual Stresses—How Dangerous are They? W. Soete. (*Metal Progress*, 1955, **67**, Jan., 108–113). In sound structures residual stresses help to propagate brittle fracture at low temperatures, affect the yield point, and increase corrosion rates. In structures or machine parts which contain minor physical discontinuities residual stresses may induce brittle fracture at low temperatures.—B. G. B.

On Residual Stresses in Statically Loaded Bars. H. Bühler. (*Arch. Eisenhüttenwesen*, 1955, **26**, Jan., 51–54). Tests on bars of 12 and 50 mm. dia. showed that residual stresses in the bar after the usual heat-treatment given constructional steels can be greatly reduced by static tensile and compression loading within the elastic limit. It is concluded that residual stresses after heat-treatment do not impair the ability of ductile steels to carry static loads.—T. G.

Residual Stress and the Compressive Strength of Steel. A. W. Huber and L. S. Beedle. (*Welding J.*, 1954, **33**, Dec., 589s–614s). An extensive investigation on the effect of residual stresses set up during cooling on the strength of compression members of structural steel is described. The report shows that the strength of axially loaded columns of 8 WF 31 shape cannot be determined from results of small coupon tests but that due consideration must be given to residual stresses. The theories described give adequate explanation of experimental behaviour. Data on the compressive properties of steel are also reported.—U. E.

Deep Drawing Sheet—Physical Charateristics Determining Quality. R. Levi. (*Ing. Mecc.*, 1954, **3**, Sept., 7–12). [In Italian]. The author studies the stresses which arise in the deep drawing of sheets and the effects of annealing and temper rolling. A general differential equation for the deep-drawing operation is established which enables an estimate of the deep-drawing qualities of sheet steel to be made.

M. D. J. B.

The Mechanical Characteristics of Metals with Particular Reference to Calculations of Plastic Working. F. Rusconi. (*Ing. Mecc.*, 1954, **3**, Oct., 33–40; Nov., 25–28). [In Italian]. After defining and describing the modulus of elasticity, yield point, ultimate strength, elongation, resistance to deformation, and work hardening, the author examines the mathematical relations associated with these properties. The diagrams normally used to illustrate these characteristics are discussed and the means of linking one property with

another is described. The author then proposes a method by which all the mechanical characteristics of a metal can be represented on a single diagram. The study deals primarily with aluminium but it can be extended to cover other metals.—M. D. J. B.

Residual Stresses after Plastic Tensile Deformation. V. Hauk. (*Z. Metallkunde*, 1955, **46**, Jan., 33–38). X-ray measurements made after plastic deformation of various steels and a non-ferrous alloy showed, in addition to the second type residual stresses, a general condition of compressive residual stress, varying in amount for different interference planes. These stress differences could not be explained by the elastic anisotropy of the individual crystallites. The compressive residual stress is conditioned by the different average yield points of the ferrite and intermetallic phases.—L. D. H.

The Thermal and Mechanical Stressing of Extrusion Tools. K. Laue. (*Z. Metallkunde*, 1955, **46**, Jan., 1–6). Conditions affecting the life of extrusion equipment are discussed, and factors making for increased efficiency are indicated. The influence of thermal stressing is emphasized.—L. D. H.

Stress Measurements in Cast Iron. H. Schlechtweg. (*Z. Metallkunde*, 1954, **45**, Dec., 690–694). The deformation law of cast iron in the as cast condition with increasing loads is established, together with the determination of material constants. The calculation of the stress state from elongation measurements of the surface is discussed, and an example is worked out.—L. D. H.

X-Ray Photographic Investigations of the Influence of Carbon Content on Residual Bending Stresses in Steel and Iron. L. Reimer. (*Z. Metallkunde*, 1955, **46**, Jan., 39–42). In contrast to measurements on pure iron, X-ray measurements of the bending residual stresses in steels of varying carbon content showed a greater bending moment in the plastically deformed portion than in the elastically deformed portion, and in the opposite sense. The relationship between the residual stresses between ferrite and cementite, and the cementite content of the steel is discussed.—L. D. H.

Arctic Regions Pose Tough Metallurgical Problems. F. W. Myers, jun. (*Iron Age*, 1955, **175**, Jan. 20, 79–82). Metallurgical problems associated with the use of metals under arctic conditions are considered. Several examples of structural failure are given. The inadequacy of ordinary steels for low-temperature use is probably the greatest cause of such failures. The 'windchill effect' is defined and is said to be a responsible factor. Materials better able to withstand the conditions are described.—D. L. C. P.

Structural Deterioration of a Steel Chain Subjected to High Temperature. (*Pact.*, 1954, Dec., 495–497). The chain was used to suspend articles in a molten salt bath. This treatment caused the chain to fail under load. The effect of this treatment on the mechanical properties of the chain is discussed.

B. G. B.

Fretting Corrosion as a Cause of Fracture of Shrink-Fit Crankshafts of Large Reciprocating Engines. F. Jaklitsch. (*Stahl u. Eisen*, 1955, **75**, Jan. 27, 97–98). The author investigated the causes of failure of crankshafts of large gas engines and found that it must be attributed to fatigue. The fatigue cracks started at areas in which fretting corrosion had reduced the alternating bend strength of the steel. In shrink-fit crankshafts small differential movements occur owing to shrinkage stresses in service and torsional and bend stresses are superimposed on these.—T. G.

The Velocity of Brittle Fracture. D. K. Roberts and A. A. Wells. (*Engineering*, 1954, **178**, Dec. 24, 820–821). Terminal velocity is shown to be a definite fraction of elastic-wave velocity. The authors confirm that for static or slowly applied loads, the energy necessary to support a brittle fracture must be provided from the available part of the elastic energy stored within the body which is cracked.

M. D. J. B.

Improved Valve Life for Automotive Internal Combustion Engines. E. J. Gay. (*J. Inst. Auto. Aeronaut. Eng.*, 1954, **14**, Dec., 278–287). Engine design, valve steels, and the causes of valve failure are discussed. Details of a test procedure for determining the operating temperatures of valves and seat inserts by means of a draw curve are given. Silchrome No. 1 or G.M-8440 for valves and SAE 3140 for seat inserts have produced draw curves with the desired slope at full-load operating temperature of most engines.

E. C. S.

The Toronto Trouble. Sir Claude Gibb. (*Elect. Times*, 1955, **127**, Feb. 17, 262–263). An investigation into the cause of failure of two 100-MW. turbo-generators at Toronto revealed that failure took place in the rotor end bells along the line of three ventilation holes The material of the bells was austenitic steel, and replacements were made from magnetic steel. It is now possible to make the bells from austenitic steel without the residual stresses originally present, and without ventilation holes.—L. D. H.

Creep and Creep Testing of Steels. T. Akutagawa. (*Tetsu to Hagane*, 1955, **41**, Jan., 48–58). [In Japanese]. The present state of knowledge of creep, creep testing, and apparatus used is reviewed, with emphasis on long- rather than short-term testing. Applications of creep data to engineering design are discussed. (30 references).—K. E. J.

Fatigue Tests of Wires for Wire Rope. E. Mikumo, T. Aida, H. Higami, and S. Sato. (*Suiyokwai-Shi*, 1954, **12**, Oct., 378–395). [In Japanese]. Rotating bend fatigue tests on rope wire of two sizes and approximately the same strength were performed. The impact tensile strength dropped suddenly after a definite number of cycles, the number being markedly lower (about 5×10^4) in the case of the thicker wire which also had a lower endurance and fatigue limit.—J. G. W.

Fatigue Studies on Components of Large Diesel Motors. P. E. Wiene. (*Rev. Gén. Mécan.*, 1955, **39**, Feb., 51–57). The importance of fatigue studies in Diesel components is first explained. Ten million cycles can be achieved during ten months operation of the motors. The influence of alloy content, heat treatment, nitriding, and shot peening on the fatigue properties of steels is reported. The building up of one metal on top of another for crankshaft construction and magneto-flux examination of piston rods for cracking are discussed. Fatigue tests on welded joints are also reported.—B. G. B.

Stress Concentration Factors—Relating Theoretical and Practical Factors in Fatigue Loading. R. B. Heywood. (*Engineering*, 1955, **179**, Feb. 4, 146–148). Theoretical stress-concentration factors such as those obtained by photoelasticity cannot, in general, be applied directly to strength values in practice, because of the differences that exist between the hypothetical material assumed by theory and the crystalline aggregate used by the engineer. Some of the causes for this discrepancy are described with particular reference to the effects of fatigue loading.—M. D. J. B.

The Comet and Design Against Fatigue. W. J. Duncan. (*Engineering*, 1955, **179**, Feb. 8, 196–200). This article formulates some of the important technical conclusions and questions which emerge from the accidents to the two Comet I aircraft in 1954 and reviews briefly the subject of the fatigue of metals and its implications for engineering design.—M. D. J. B.

An Evaluation of the Recovery Theory of Creep. H. H. Bleakney. (*Canad. J. Techn.*, 1955, **33**, Jan., 56–66). The recovery theory of creep was defined by Bailey as the balance of the rate of production of strain-hardening by distortion and its removal by thermal action. The author discusses the three main objections to the theory and suggests that the opposing influence of strain-hardening and thermal softening, modified by factors introduced by metallurgical instabilities, are the fundamental verities of creep.—E. C. S.

A New Machine for Endurance Tests with Stress Cycles of Variable Amplitudes. H. K. Leber. (*Gen. Motors Eng. J.*, 1954, **1**, Sept.-Oct., 16–20). A machine incorporating a resonance and a hydraulic drive and designed to subject vehicle parts and assemblies to endurance tests is described. The operation of the machine demands that all possible loads and frequencies which the vehicle will encounter be known, but tests are carried out in a fraction of the time required for road tests.—J. E. J.

An Automatic Load Control for Tuning-Fork Fatigue Test Equipment. R. A. Gallant and E. K. Benda. (*Gen. Motors Eng. J.*, 1954, **1**, Nov.-Dec., 6–9). A brief description is given of a tuning-fork type of fatigue-testing machine, and the problem of sensitive load control is discussed. Details are given of a servo control loop which uses the specimen load as a basis of load control. Strain gauges are used to measure the stress in the system, and the difference between the gauge output and a reference voltage represents the error between actual and required load on the specimen. The error signal is fed back to control the exciting motor

on the fork. The variation in stress is within ± 2% of the desired value.—E. A. C.

Determinations of the Maximum Test Load in Hardness Testing. T. Todoroff. (*Maschinenwelt Elektrotechnik*, 1954, **9**, Oct., 316–318). The construction of a nomogram is described, from which the maximum load or minimum thickness of the test piece can be selected for hardness testing. L. D. H.

Investigations of the Relationship Between the Vickers Microhardness and the Load. H. Bückle. (*Z. Metallkunde*, 1954, **45**, Nov., 623–632; Dec., 694–701). Oblique illumination and interferometric evaluation indicated that the deviation of the impression from the rectangular form is due to ridging. No simple method of evaluation is available, of the curve log P/log d, and the use of standard curves constructed from reference loads is recommended for comparison purposes.—L. D. H.

Hardness and Plasticity of Metals. J. H. Zaat. (*Metalen*, 1954, **9**, Nov. 30, 353–358; Dec. 15, 373–380). [In Dutch]. The true stress/strain curve describes the mechanical behaviour of a metal under the influence of a uni-dimensional state of stress but recent theory of plasticity implies that the stress/strain curve must indicate the mechanical behaviour under any given multi-dimensional state of stress. Thus, the conceptions of equivalent stress and equivalent deformation were introduced. The equivalent stress is a function of the main stresses and the equivalent deformation is a function of the relevant main deformations. The equivalent stress and the equivalent deformation are so selected that any given test in which plastic deformation occurs produces a true stress/strain curve. The relationship is shown between plastic properties of a metal as represented by the stress/strain curve and the hardness. Each hardness value is, in effect, a point on the stress/strain curve. Methods of hardness measurement which produce impressions of similar form under varying load always give the same point on the curve, irrespective of the magnitude of the impression. Hardness measurements which involve dissimilar impressions under varying load give a different point on the curve when the load is varied. This latter type of hardness measurement can thus be used to determine the universal stress strain curve.—R. S.

Study on Heat-Resisting Steel (VI). E. Asano. (*Tetsu to Hagane*, 1954, **40**, Nov., 1072–1079). [In Japanese]. The precipitation phenomena of Timken 16–25–6 were studied by micro-hardness testing. Excessive ageing and precipitation treatment resulted in similar hardness at the grain boundary, near the boundary, and in the centre of the grain. In general, at the early stages of precipitation, hardening was greater in the centre of the grain but at a later stage an intermediate maximum hardness developed near the grain boundary.—K. E. J.

How to Control Hydrogen Embrittlement in 12 Chrome Steels. A. E. Durkin. (*Iron Age*, 1954, **174**, Dec. 9, 154–156). Experiments on the hydrogen embrittlement (a source of premature cracking) of 12% Cr steel are described, and preventive measures deduced. Material tempered in the 1000° F. range showed less susceptibility than that tempered in a lower range. Organic protective coatings are also effective. D. L. C. P.

The Fundamental Process of Magnetization in Alni and Alnico Permanent-Magnet Alloys. H. Fahlenbrach. (*Techn. Mitt. Krupp*, 1954, **12**, Dec., 177–184). An outline of present day knowledge of fundamental processes in modern materials for permanent magnets is illustrated by results obtained in investigations in Alnico-400 permanent magnets. Using an electron microscope, the heterogeneity of structure found by Nesbitt and Heidenreich in Alnico-400 single and polycrystals after heat-treatment at 800° C. was confirmed. By oxidation of the powder at 500° C. in KNO_3–$NaNO_3$ melts followed by chemical separation it was shown that the more easily oxidizable constituent apparently contains more aluminium and iron, and the less easily oxidized portions more cobalt, nickel, and copper than the original powder. The former constituent shows a lower magnetic saturation and lower Curie point, and the latter a higher saturation than, and the same Curie point as, the original powder. L. D. H.

Permanent Magnet Alloys. J. Lomas. (*Machinery Lloyd, European Ed.*, 1954, **26**, Nov. 13, 77–79). Recent studies of the properties, treatment, and effect of variations in composition on the properties of V–Co–Fe permanent magnet alloys are described.—J. E. J.

The Magnetostriction Constants of Silicon Steel. H. Takaki and Y. Nakamura. (*J. Phys. Soc. Japan*, 1954, **9**, Sept.-Oct., 748–752). Magnetostriction and magnetization of cylindrical, single-crystal pods of 2·6%, 3·2%, and 4% silicon steel, with various crystallographic orientations were measured at room temperature. Kaya's law concerning remanent magnetization held; λ_{111} and K_1 decreased almost linearly with silicon content, but λ_{100} had a pronounced minimum at about 2% silicon.—J. G. W.

The Magnetic Properties and their Temperature Dependence of Ferro-magnetic Alloys with an Order–Disorder Transformation. I. Ni_3Fe. T. Taoka and T. Ohtsuka. (*J. Phys. Soc. Japan*, 1954, **9**, Sept.-Oct., 712–722). The temperature dependence of magnetic properties of Ni_3Fe was measured at a fixed state of order, with particular attention to the order–disorder transformation at 490° C. The saturation magnetostriction decreased monatomically with temperature at a fixed state of order, and increased with formation of order at a constant temperature.—J. G. W.

The Magnetic Properties and their Temperature Dependence of Ferro-magnetic Alloys with an Order–Disorder Transformation. II. Ni_3Mn. T. Taoka and T. Ohtsuka. (*J. Phys. Soc. Japan*, 1954, **9**, Sept.-Oct., 723–729). The change of magnetic properties with superlattice formation was measured on Ni_3Mn. The Curie point was found to increase from below room temperature in the disordered state to over 490° C. in the ordered state and large and prolonged magnetic after effects were present at intermediate states of order.—J. G. W.

On the Magnetic Ageing of Pure Iron. M. Asanuma and S. Ogawa. (*J. Phys. Soc. Japan*, 1955, **10**, Feb., 161). The initial susceptibilities of commercially pure iron, tempered at about 130° C., were measured as function of tempering time. Additional experiments with hydrogen-, carbon-, and nitrogen-treated specimens confirmed that the precipitation of nitrogen and carbon is responsible for the variation of initial susceptibility, with nitrogen being the dominant factor. J. G. W.

The [110] Magnetostriction of some Single Crystals of Iron and Silicon–Iron. E. W. Lee. (*Proc. Phys. Soc.*, 1955, **A, 68**, Feb. 1, 65–71). Magnetostriction depends on crystal width in a similar way to magnetization behaviour. In general, domain vectors in the demagnetized state are not uniformly distributed along all the easy axes.—K. E. J.

Ferromagnetic Resonance in Iron–Nickel Alloys. R. Hoskins and G. Wiener. (*Phys. Rev.*, 1954, **96**, Nov. 15, 1153–1154). Ferromagnetic resonance experiments on disc-shaped bulk samples have not confirmed Bagguley's claim that a sharp decrease in the g-value occurs between 30% and 50% nickel in Fe–Ni alloys. It is suggested that line-broadening caused inaccuracy in the previous measurements.—J. O. L.

Magnetic Hardness-Testing. (*Aircraft Prod.*, 1954, **16**, Dec., 491–493). This method of non-destructive testing is based on the interdependence of hardness of a material and its magnetic remanence or retentivity, i.e. magnetic flux remaining after removal of the magnetizing force. Two machines based on this principle are described, and provide a rapid method of inspecting ferrous parts.—T. E. D.

Iron Losses at High Magnetic Flux Densities in Electrical Sheet Steels. F. Brailsford and C. G. Bradshaw. (*Inst. Elec. Eng.*, Advance Copy M1794, 1955). A thermal method for determining the total iron losses at 50 c./sec. in a number of silicon–iron materials and in one sample of cobalt iron up to an approximate induction of 2·4 We/sq. in. is described. Empirical formulæ are given to determine the loss at high inductions from a knowledge only of the losses at lower densities.—E. C. S.

Mutual Inductance Bridge and Cryostat for Low-Temperature Magnetic Measurements. R. A. Erickson, L. D. Roberts, and J. W. T. Dabbs. (*Rev. Sci. Instruments*, 1954, **25**, Dec., 1178–1182). A mutual inductance bridge and cryostat is described for the measurement of susceptibilities with nitrogen from 77° K. down to adiabatic temperature measurements.—L. D. H.

Apparatus for Measurement of Sensitivity of Electrical Resistance of Wires to Strains. G. C. Kuczynski and P. F. Stablein. (*Rev. Sci. Instruments*, 1954, **25**, Dec., 1222–1223).

Electrical Conductivity and Thermo-electric Motive Force in MgO Single Crystal. E. Yamaka and K. Sawamoto.

(*J. Phys. Soc. Japan*, 1955, **10,** Mar., 176–179). Measurements of electrical conductivity and of T.E.M.F. were measured on MgO single crystals in range 650–1000° C. Slope of $\log\sigma$ *v.* $1/T$ curves was 2·3 eV; T.E.M.F. ranged from 0·1 to 10 mV./°C. depending on excess magnesium. It was concluded that electrons are charge carriers and originate from impurity levels of oxygen vacancies or interstitial magnesium.—J. G. W.

The Electrical Resistance of Cast Irons. (*Fonderie*, 1954, Nov., 4241—4246). The effects of carbon, silicon, manganese, sulphur, phosphorus, nickel, chromium, molybdenum, copper, and aluminium on the electrical resistivity of cast iron are reviewed, together with those of microstructure and heat-treatment.—B. C. W.

Thickness Measurement by Ultrasonics. (*Instruments in Industry*, 1954, **1,** Dec., 235–238). This article commences with an outline of the principles underlying the measurement of metal thickness by ultrasonic waves, including the use of harmonics. These principles are then illustrated by means of several industrial applications.—L. D. H.

The Automatic Testing of Welds by Ultrasonics. G. A. Homès. (*Rev. Soudure*, 1954, **10,** (4), 229–233). Ultrasonic techniques for the testing of welds are described. Particular reference is made to the industrial testing of tubes.—M. D. J. B.

Preliminary Experiments on the Temperature-wave Method of Measuring Specific Heats of Metals at Low Temperatures. D. H. Howling, E. Mendoza, and J. E. Zimmerman. (*Proc. Roy. Soc.*, 1955, **A, 229,** Apr. 5, 86–109). The method gives reliable results in the helium range, using simple procedures, and will probably be useful below 1° K.—K. E. J.

Investigations on the Development of Technical Arrangements for Sonic Treatment for Metallurgical Use, with Particular Reference to Sound Conduction Problems and the Electrodynamic Procedure. H. J. Seemann and H. Staats. (*Giesserei Technisch-Wissenschaftliche Beiheft*, 1954, Dec., (14), 753–759). The general field of the vibration treatment of metals is first considered. The applications include degasification and purification of metals, grain refinement during crystallization, and dispersion effects. Basic considerations of problems of sound conduction are enumerated, and experimental results on the temperature dependence of the velocity of sound and damping in metallic materials are given. The production of vibrations in the material itself by mechanical and electro-dynamic methods is then described. Constructive proposals are made for improvement in efficiency.—R. J. W.

Investigations of the Influence of the Structure on the Extinction of Ultrasonic Waves in Metallic Materials. H. J. Seemann and W. Bentz. (*Z. Metallkunde*, 1954, **45,** Dec., 663–669). The ultrasonic wave-scatter obtained with a number of metallic substances was investigated. Echoes from coarse-grained Armco iron specimens were attributed mainly to scatter reflections. Specimens of high-chromium ferritic steels were also studied.—L. D. H.

Adaption of a Standard X-Ray Powder Camera for Work at Low Temperatures. J. Thewlis and A. R. Davey. (*J. Sci. Instruments*, 1955, **32,** Feb., 79). A Unicum 19-cm. camera is adapted so that gas from boiling liquid nitrogen is passed over a powder specimen. Temperatures down to −150° C. can be obtained, and regulated to ± 1° C.—L. D. H.

Testing of Engineering Materials. H. G. Harper. (*Coventry Eng. Soc. J.*, 1955, **36,** Jan.-Feb., 4–12). This paper deals with some simple non-destructive tests and with mechanical testing including the Vickers hardness test.—E. C. S.

Development and Present State of Non-destructive Materials Testing by Means of Ultrasonics. E. K. Reyer. (*Technik*, 1955, **10,** Jan., 7–16). The development of ultrasonic testing in the East-German Republic is surveyed. Both methods and equipment are considered, with particular emphasis on oblique radiation.–J. G. W.

Gamma Radiography. F.-C. Fontenay. (*Métaux-Corrosion-Indust.*, 1955, **30,** Jan., 9–17). The use of gamma radiography for non-destructive testing is discussed. Cobalt 60, iridium 192, caesium 137, and thallium 170 are used for sources of gamma rays and the selection of the particular source depends on the nature of the material to be radiographed. Examples are given of source units and their use.—B. G. B.

Practical Non-Destructive Testing of Arc Welds. H. Rosenheim. (*Engineer Foundryman*, 1955, **19,** Jan., 59–64, 67). X-ray, gamma-ray, ultrasonic, and magnetic methods of testing welds are explained and the respective advantages of each method are discussed.—A. D. H.

Safety in Industrial Radiography. V. E. Pullin. (*Engineer*, 1955, **199,** Feb. 11, 186). The author stresses the necessity for adequate precautions in the ever-increasing uses of X-rays and radioactive agents in industry and emphasizes the fact that strict obedience to protective rules entirely eliminates the dangers which potentially exist.—M. D. J. B.

The "Aero" Magnetic Powder for the Electro-magnetic Detection of Surface Flaws in Steels. J. Šubert and J. Jareš. (*Slévárenství*, 1955, **3,** (3), 75–77. [In Czech]. The manufacture and use of this new powder of Czechoslovak manufacture are described. The powder is satisfactory in use, equivalent in properties to powders hitherto imported.—P. F.

Artificial Radioactive Isotopes and Their Use in Industry. A. Kuhn. (*Hutnické Listy*, 1954, **9,** Dec., Supplement 45–46). [In Czech]. The principal methods of using radioactive isotopes, and the basic types of detector circuits, are considered.—P. F.

The use of Radioactive Isotopes for Thickness Gauging. J. Gumanskij. (*Hutnické Listy*, 1954, **9,** Dec., Supplement 42–44). [In Czech].

Sources of Radiant Energy for Measurements without Contact. J. Petr. (*Hutnické Listy*, 1954, **9,** Dec., Supplement 38–39). [In Czech].

Non-Destructive Testing of Metals by X-Ray Analysis. M. Robba. (*Ing. Mecc.*, 1954, **3,** Dec., 25–30). [In Italian]. The author discusses the main features of gamma-ray testing of metals and reviews the possibilities and advantages of X-rays as compared with other non-destructive methods of testing. Information is given on the most commonly used radioactive isotopes and on the practical aspects of γ-ray photography. This includes details on the formation of radiographic images (transmission and absorption of radiations, density of blackening, and on the quality of the images (sensibility, contrast, definition, exposure). Results obtained in industrial testing of weldings and castings are discussed and possible hazards to personnel are briefly outlined.—M. D. J. B.

Spectrographic and X-Ray Investigations of Spherolitic Graphite from Spheroidal Graphite Cast Iron. W. Deuchler. (*Giesserei Technisch-Wissenschaftliche Beihefte*, 1954, Dec., (14), 745–749). Methods of isolating the spherolitic particles are considered, and the author's method of mechanical isolation is described in detail. Chemical, spectrographic, and X-ray investigations were carried out on these particles and are reported. It was established that there were two kinds of spheroids, magnetic and non-magnetic. X-ray, spectrographic, and microscopic investigations were also carried out on kish.—R. J. W.

Research on a New Method of Deciphering Debye-Scherrer Diagrams. G.-A. Homès and J. Gouzou. (*Rev. Mét.*, 1954, **51,** Nov., 749–757). In the identification of non-metallic inclusions in a steel, the presence of an element in solid solution may so modify the crystallographic parameters of a constituent that definite identification may be impossible. A method is proposed which overcomes these difficulties. It depends on the successive determination of a certain number of plane sections of the reciprocal lattice.—G. E. D.

Industrial Experiences with the Magnatest-Q Apparatus. H. Beuse and H. Koelzer. (*Z. Metallkunde*, 1954, **45,** Dec., 677–686). Laboratory tests are described on the classification, by means of the Magnatest-Q apparatus, of bright-drawn steel rods and normalized parts, the non-destructive determination of variations in physical properties of mass-produced parts, and investigation of faults in steel for rods and screws.—L. D. H.

An X-Ray Thickness Gauge for the Measurement of Hot-Rolled Strip Steel. F. H. Gottfeld and D. Tidbury. (*J. Brit. Inst. Radio Eng.*, 1954, **14,** Dec., 622–626). The principles of the constant and variable absorption methods of measuring thickness by means of X-radiation are outlined, and the design and use of an X-ray thickness gauge for continuous measurements in hot-rolled strip steel are described.—L. D. H.

Present Knowledge of the Creep of Steels for Boilers and Tubing Operating at Elevated Temperatures. O. L. Bihet. (*Rev. Soc. Roy. Belge Ing. Indust.*, 1955, Jan., 5–20). The measurement of the creep properties of steels is explained and the theory of creep failure briefly considered. The selection of steels for use in boilers and tubing for steam power stations is discussed. The creep and rupture properties of some of the steels used are reproduced in graphical form. The importance of the rupture strength of the steels used in addition to their creep properties is stressed.—B. G. B.

Determination of Thermal Conductivities at High Temperatures. Sir K. S. Krishman and S. C. Jain. (*Brit. J. Appl. Phys.*, 1954, **5,** Dec., 426–430). Observations of the temperature distribution along metal filaments electrically heated *in vacuo* can be employed for thermal conductivity calculations. In short filaments the distribution is parabolic near the centre, while in longer ones it is logarithmic at some distance from mid-point. The method has been used for platinum between 1300° and 1800° K.—J. O. L.

The Physical and Computing Significance of an Electrical Analogue of Creep and Recovery. A. J. Kennedy. (*Brit. J. Appl. Phys.*, 1955, **6,** Feb., 49–58). The characteristics of creep in metals can be accurately simulated by a multi-stage non-inductive transmission line, operated by an automatic voltage programme control. Data from short-term metallurgical examination, other than temperature effects, can be transformed to indicate the behaviour of material over longer periods. A more complicated device could be built to obtain more comprehensive information in shorter operating times.—J. O. L.

On the Representation of Rheological Results with Special Reference to Creep and Relaxation. P. Feltham. (*Brit. J. Appl. Phys.*, 1955, **6,** Jan., 26–31). From the work of Weichert, Boltzmann, Zener, and Andrade, the validity of a theory postulating the existence of relaxation centres having constant heats of activation in all solids is indicated. Experimental results on a wide range of materials confirm this and the applicability of Nutting's law of deformation as a general approximation is demonstrated.—J. O. L.

Measurement of the Electrical Resistance of Metals and Alloys at High Temperatures. P. Chiotti. (*Rev. Sci. Instruments*, 1954, **25,** Sept., 876–883). An A.C. potentiometric method is described for measuring the electrical resistance of metals at high temperatures, the test bar being heated electrically.—L. D. H.

Design of Extensometer for Creep Studies. B. R. Gossick. (*Rev. Sci. Instruments*, 1954, **25,** Sept., 907–909). An extensometer is described which measures the displacement of a specimen by the displacement of a metal core, to which it is attached, within a mutual inductance bridge.—L. D. H.

Behaviours of Hydrogen in Steel Subjected to Elastic Stress (I). H. Shimoda and S. Onodera. (*Tetsu to Hagane*, 1954, **40,** Nov., 1060–1066). [In Japanese]. Qualitative experiments were made to investigate the effect of stress on the flaking of steel caused by hydrogen. Under tensile or compressive stresses of <12 kg./sq. mm., hydrogen evolution was more marked as the magnitude of the stress increased and when the concentration gradient of hydrogen near the surface was sharp.—K. E. J.

The Diffusion of Hydrogen In Iron and Ferritic Steels. E. W. Johnson and M. L. Hill. (*Acta Met.*, 1955, **3,** Jan., 99–101). The authors report the investigation of the evolution of hydrogen from iron of 99·9% purity at 385–900° C. They conclude that slowly diffusing or residual hydrogen is a real effect detected only after the rapidly diffusing hydrogen has been removed. The amount of residual hydrogen decreases as the temperature is raised and is affected by the previous thermal history of the sample.—A. D. H.

The Effects of Oxygen and Nitrogen in Solid Iron and Steel. L. C. Bogan. (*Australian Inst. Met.*, 1954, *Symposium on Gases in Metals*, Nov. 11, 1954, 21–27). The principal phenomena of economic interest arising from the presence of oxygen and nitrogen in ferrous metals are described. Whilst both gases dissolve interstitially in both alpha and gamma iron, the effects of solid solution are more important in the case of nitrogen. Nitrogen is of special interest in understanding phenomena associated with plastic flow, such as the sharp yield point, blue brittleness, and strain- and age-hardening. In steels, oxygen is of interest mainly in relation to the effects of the deoxidation products, namely, non-metallic inclusions. The suppression of the solid solution effects of both gases, by fixing them as components in alpha iron, by the addition of aluminium, titanium, or zirconium is described.—P. M. C.

Some Fundamental Aspects of Gas-Metal Systems. G. M. Willis. (*Australian Inst. Metals*, 1954, *Symposium on Gases in Metals*, Nov. 11, 1954, 1–5). The electronic nature of metals is related to their absorption and catalytic properties, and the author discusses and differentiates between gas solubilities which are limited by precipitation of an intermediate phase and solubilities where only gas and metal phases exist. The nature of the bonding of gases in metals is discussed and the importance of energy and entropy terms in interstitial solutions is assessed and used to show how the solubility of oxygen in α iron is limited by the properties of the oxide FeO. The models used in statistical treatments of these systems are described briefly and are shown to be related to models for the process of diffusion.—P. M. C.

Heat-Resisting Steels for Steam Turbines. Z. Eminger and Pokorný. (*Hutnické Listy*, 1955, **10,** (1), 3–10; 1955, **10,** (2), 76–81). [In Czech]. The creep and relaxation properties, fatigue strengths, impact values (after various periods of 20,000-hr. creep tests), and other properties of an austenitic Cr–W–V steel were determined. Both steels were found to be essentially equivalent from the point of view of their intended applications, both at high and ordinary temperatures. On the basis of tests carried out, information and guidance is provided for the designer, producer and research worker.—P. F.

Properties and Structure of Iron–Cobalt Alloys with 50% Co and Small Additions of Vanadium. G. Baer and H. Thomas. (*Z. Metallkunde*, 1954, **45,** Nov., 651–655). Measurements of the electrical resistance, thermal expansion, and structure of the Fe–Co–V system in the range 50% Co and up to 4% V gave results somewhat different from the accepted figures. The α/γ transformation has a strong temperature hysteresis, and resembles the irreversible transformation in the Fe–Ni system. The solubility, dependent on temperature, of V in the α-solid solution gives rise to ageing phenomena. Non-homogeneity of the structure and phase distribution are apparently due to selective oxidation.—L. D. H.

The Solution of Gases in Liquid and Solid Metals. A. E. Jenkins. (*Australian Inst. of Met.*, 1954, *Symposium on Gases in Metals*, Nov. 11, 1954, 6–15). Recent investigations concerning the solubility of gases in metals are summarized. The fundamental laws of solution are discussed from the thermodynamic viewpoint, and it is shown that an analysis using methods of statistical mechanics can lead to a more complete understanding of the solution process. Some of the more important investigations into gas–metal equilibria published since 1949 are discussed and attention is also draw to the difficulties associated with the various experimental techniques. (65 references).—P. M. C.

Influences of N and Cb on the Properties of LCN–155 and of Cb on those of S–816. K. Deguchi. (*Tetsu to Hagane*, 1954, **40,** Dec., 1119–1127; 1955, **41,** Feb., 134–139). [In Japanese]. Studies on several heat-resisting steels included investigations of the effects of N and Nb on microstructures as-cast and forged, changes of hardness and structure after solution treatment, ageing and working, mechanical properties at room and elevated temperature and welding behaviour. The results are summarized in equilibrium diagrams.—K. E. J.

Effect of Arsenic, Copper, Tin and Molybdenum on Impact Properties of Dead Soft Steel. H. Sawamura, T. Mori, K. Kido, and K. Fujita. (*Tetsu to Hagane*, 1955, **41,** Jan., 23–31). [In Japanese]. Tests were made between room temperature and 900° C. on a steel containing 0·04% C, 0·2% Si, and 0·4% Mn. The maximum allowable limits for the four impurities, in respect of deformability, are estimated, and effects on ingot shape, heating temperature, and time, etc., are considered.—K. E. J.

Some Experiments on 13% Chromium Cast Steel. S. Maekawa and T. Yamashita. (*Tetsu to Hagane*, 1955, **41,** Jan., 42–47). [In Japanese]. Optimum compositions for corrosion-resistance, structural properties, high strength, etc., were determined. Machinability is best in the annealed state. The best mechanical properties are obtained by quenching at 100° C. and tempering at 700–780° C. Annealing-brittleness can be minimized by normalizing. Details are given of welding procedures.—K. E. J.

Studies of Ni–Cu, Cr–Cu and Ni–Cr–Cu Hardened Steels. H. Laplanche. (*Mét. Constr. Mécan.*, 1955, **87,** Feb., 107–117). A comprehensive account of the properties of these steels, which contain about 1% copper, is presented. The influence of composition and heat treatment on the mechanical properties is given in a series of graphs and tables. Methods of carrying out the heat-treatment to obtain the optimum mechanical properties are explained.—B. G. B.

Enthalpy and Specific Heat of Four Corrosion-Resistant Alloys at High Temperatures. T. B. Douglas and J. L. Dever. (*J. Res. Nat. Bur. Stand.*, 1955, **54,** Jan., 15–19). Specific

heats accurate to ± 2% from 0° to 900° C. for 80% Ni–20% Cr and two stainless steels, and from 0° to 300° C. for Monel metal are reported.—B. G. B.

Alloying and Heat Treating Spherulitic Graphite Cast Iron. C. C. Reynolds and H. F. Taylor. (*Trans. Amer. Found. Soc.*, 1954, **62,** 181–194). Results to show the effects of silicon, manganese, chromium, and nickel on the microstructure and mechanical properties of spheroidal graphite cast iron are presented and discussed. The effects of the alloying elements on graphite, the solid solution hardening of ferrite, pearlite, and on the as-cast microstructure are discussed, and the effects of heat-treatment on microstructure and properties are briefly considered.—B. C. W.

A Turbine-Blade Alloy, Castable and Low in Cobalt and Columbium. W. Siegfried and F. Eisermann. (*Metal Progress*, 1955, **67,** Jan., 141–146). An outline is given of the development of an alloy for use at high temperatures, capable of investment casting and economical in scarce alloying metals. The alloy contains 0·1% C, 0·2% N, 18% Cr, 17% Ni, 4% Mn, 4% Co, 1% Nb, 2% W, 3% Mo, balance Fe. Additional work shows that cast turbine blades are no more susceptible to thermal shock than the forged blades successfully used in gas turbines.—B. G. B.

Proper Treatments Preserve Properties of Types 321 and 347 Stainless. H. Brown. (*Iron Age*, 1954, **174,** Nov. 25, 93–95). Types 321 and 347 stainless steels belong to the 18/8 group, and are stabilized with titanium and niobium, respectively. Troubles which may arise in the use of these steels (e.g. sensitization, zinc contamination, edge cracking) are considered and corrective measures explained.—D. L. C. P.

High Strength 'ALS' Steels for Lightweight Construction. A. Bartocci. (*Métaux-Corrosion-Indust.*, 1955, **30,** Jan., 18–33). The development in Italy of new low-alloy steels suitable for welding and having high strength is described. The steels contain low carbon, 0·80–1·20% Mn, 0·5–1·0% Si, 0·6–1·10% Cr, 0·5–1·5% Ni, and small molybdenum and vanadium contents. The microstructure, physical properties, and welding characteristics are given. The steels possess excellent resistance to brittle fracture and examples of their application are mentioned.–B. G. B.

Recent Progress in Alloy and Special Steels. G. T. Harris and E. Johnson. (*Metallurgia*, 1955, **51,** Jan., 17–23). A survey is made of recent published information concerning these steels. The following types of steel are considered: constructional, extra high tensile, cold-work, hot-work, and high-speed tool, heat-treatment, corrosion-resisting, and high-temperature. The continuous casting of alloy steel is also mentioned. (36 references.)—B. G. B.

The Wear of Steel Rails: a Review of the Factors Involved. J. Dearden. (*Proc. Inst. Civil Eng.*, 1954, **3,** Pt. 2, Oct., 456–480). The measurement of rail wear in the track by means of the Shaw contorograph is described, and profile and lateral wear is discussed. The effect of composition and heat-treatment on wear is discussed for basic O.H. and acid Bessemer steels, high-carbon and medium-manganese steels, sorbitic and normal steels, grain-controlled steel, high-phosphorus steel, and for the special rails used in experimental tracks at Chadwell Heath and Kibworth. The effect of rail design on wear is discussed with particular reference to flat-bottom *v.* bull-head rails and rails with welded inserts. An account is given of the effect of corrosion on wear and of the relative effect of traffic and corrosion. A series of examinations of the running surface is described.—J. E. J.

The Planning and Installation of a Laboratory. (*Engineering*, 1955, **179,** Feb. 11, 173–174). This article summarizes a lecture given by J. E. Knight of the Ministry of Works on the methods of planning the services and layout of a laboratory.—M. D. J. B.

METALLOGRAPHY

Metallography of Delta-Ferrite: Parts II and III. K. Kuo. (*J. Iron Steel Inst.*, 1955, **181,** Oct., 128–137). [This issue].

Colour Metallography of Ferrous Alloys. A. Scortecci. (*Gazz. Chim. Ital.*, 1954, **84,** Nov.-Dec., 1254–1263). [In Italian]. After a brief survey of the various techniques used in metallography, the author describes a method which combines etching by solution followed by oxidation by heating in air. Methods of preparing surfaces are discussed and experimental techniques are described. Details of the results obtained are given. (41 references).—M. D. J. B.

A Microscopical Examination of Samples of Iron Containing Titanium-bearing Inclusions. F. B. Pickering. (*J. Iron Steel Inst.*, 1955, **181,** Oct., 147–149). [This issue].

Frontal Diffusion in Technical Iron. V. I. Arkharov, K. A. Efremova, S. I. Ivanovskaya, A. K. Shtol'ts and B. A. Yunikov. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **89,** 2, 269–270). [In Russian]. The diffusion of a number of elements (Ni, Pd, Al, Cu, Cr) in iron was investigated. The shape of the diffusion front (either straight or with infiltration along the intercrystalline boundaries) was shown to depend on the nature of the diffusing metal and the presence of small amounts of other elements in the iron.—V. G.

The Heterogeneity of Austenite. I. A. Oding and M. G. Lozinskii. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **89,** 2, 275–278). [In Russian]. The heterogenity of the structure of austenite grains at high temperatures was investigated. Samples of an austenitic steel were heated to a temperature of 1200° C. in a vacuum of 10^{-5} mm. The apparatus is described. By selective evaporation of the metal, the structure of the samples was made visible. The boundaries and structural differences of the original and recrystallized grains, and considerable segregation inside the grains were observed.

Grain Boundary Films in Boron Steels. J. W. Spretnak and R. Speiser. (*Trans. Amer. Inst. Min. Met. Eng.*, 1953, **197:** *J. Met.*, 1953, **5,** Mar., 445–446). The authors examine the theory that the hardenability produced by boron in steel is caused by the formation of a boron film completely surrounding the austenite grain. It is concluded that this theory is most unlikely, but the possibility of adsorption effects involving boron in solid solution in austenite appears to be of primary importance.—G. F.

Carbides in High-Speed Steels. N. T. Chebotarev. (*Symposium* 30 "*Structure and Properties of Steel*", *Metallurgizdat, Moscow*, 1951, 256–269). Data available in the literature on the structure of carbides in high-speed tool steels are discussed. An X-ray investigation of carbide residues obtained by electrolysis of three W–Cr–V high-speed steels and a micrographic study of sinters made from them at 1500° C. and 1700° C. are described.—V. G.

Simple Extrusion Press for Preparation of Specimens of Optimum Thickness for X-Ray Diffraction Powder Photographs. M. Kossenberg. (*J. Sci. Instruments*, 1955, **32,** Mar., 117–118).

A Reflexion Electron Microscope. V. E. Cosslett and D. Jones. (*J. Sci. Instruments*, 1955, **32,** Mar., 86–91). The construction and operation are described of an electron microscope for examining solid surfaces by reflexion at grazing incidence.—L. D. H.

Simple Reflexion-Transmission Stage for an Electron Microscope. K. Amboss. (*J. Sci. Instruments*, 1955, **32,** Mar., 116).

Photographing Stretcher-Strain Markings with the Vickers Projection Microscope. T. D. Boxall and B. B. Hundy. (*Metallurgia*, 1955, **51,** Jan., 52–54). A technique is described for the photographing at magnification of × 3 and × 15 of stretcher-strain markings on sheet for which the angles of lighting and viewing are very critical.—B. G. B.

Modern Microscopy. A. E. J. Vickers. (*Research*, 1955, **8,** Jan., 17–21). An introductory survey describes historical developments and the present position in the fields of light, ultraviolet light, fluorescent, phase contrast, interference, polarized light and electron microscopy, and dark-ground illumination.—K. E. J.

A Simple Microscope Attachment for Observing High-Temperature Phenomena. J. H. Welch. (*J. Sci. Instruments*, 1954, **31,** Dec., 458–462). The attachment consists of a small, electrically-heated thermocouple in the form of a loop which holds a bead specimen in contact with the thermojunction. Current is from a normal 50 c/s supply, a vibrating switch allowing the heating current to flow only during alternate half-cycles. Power dissipated at the maximum temperature of 1750° C. is about 6 W.—L. D. H.

High Temperature Furnace for the Electron Microscope. N. Takahashi, K. Itoh, T. Itoh, M. Watanabe, K. Mihama, and T. Takeyama. (*Métaux-Corrosion-Indust.*, 1954, **29,** Nov., 431–437). An illustrated description is given of an attachment for an electron microscope which enables the specimens to be heated to temperatures up to 1000° C. The

structure of Cu–Al alloys by transmission techniques and Al–Mg–Si alloys by reflection techniques have been studied and a number of photomicrographs are reproduced. The method is stated to be extremely useful and of equal value with transmission or reflection methods.—B. G. B.

Use of the Electron Microscope for Investigating Steel Structures. F. van Wijk and J. A. B. van Dijk. (*Metalen*, 1954, **9**, Dec. 31, 389–394). [In Dutch]. Electron microscope examination of cold-worked troostite and the preparation method are described. A positive replica method and an improved method are used. Residual austenite, difficult to observe with the optical microscope, is examined.—R. S.

CORROSION

The Corrosion Resistance of Wrought Iron. J. P. Chilton and U. R. Evans. (*J. Iron Steel Inst.*, 1955, **181**, Oct., 113–122). [This issue].

Corrosion by Alternating Current. H. F. Schwenkhagen. (*Werkstoffe Korrosion*, 1955, **6**, Feb., 63–71). After reporting the results of laboratory tests on the corrosion of mild-steel electrodes by A.C., D.C., and mixtures of both in cells containing sodium chloride solution or soil as an electrolyte, the author describes his practical experience of the corrosion of earthing plates at generating stations. He concludes that under practical conditions corrosion by A.C. as such is negligible and is masked by the effects of D.C. corrosion caused by the electrical connection of dissimilar metals. In his view earths should be made of the same metal as the structure that is to be earthed, i.e., in practice of steel or galvanized steel; the use of copper for this purpose should be avoided.

Mineral Oils and Greases in Temporary Rust Protection. W. Presting and G. Keil. (*Technik*, 1955, **10**, Apr., 232–235). Work on enhancing anti-rust properties of mineral oils and greases by suitable anti-corrosive additives is reported.

MISCELLANEOUS

How American Industry is Attacking the Problem of Materials Handling. J. R. Bright. (*Inst. Mech. Eng., Preprint*, 1953, Apr. 17). The author clarifies the major objectives of a materials-handling programme, shows how progressive companies are organizing materials handling; and describes the scope of a good materials handling programme and the type of individual to be placed in charge. Techniques for analysing materials-handling problems, and the characteristics of basic handling devices are presented.

Research in the Cutlery Industry. C. N. Kington. (*Metal Treatment and Drop Forg.*, 1953, **20**, Mar., 119–122). The structure, organization, and aims of the recently formed Cutlery Research Council are described. The research programme will eventually cover investigations into the composition and properties of stainless steel for cutlery; design, life and defects of dies and tools; and the possibility of introducing mechanical aids to assist handwork.—P. M. C.

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EDGAR C. BAIN, D.Sc.

EDGAR C. BAIN, Vice-President, Research and Technology, United States Steel Corporation, was born near Marion, Ohio, attended High School there, and then entered Ohio State University, from which he received the degree of B.Sc. (Chem. Eng.), M.Sc., and D.Sc. His early work was at the United States Bureau of Standards, which he left to become successively Assistant in Chemical Engineering at Ohio State University, and Instructor in Metallography and Pyrometry at the University of Wisconsin.

He served as Chemical Engineer for the B. F. Goodrich Company in 1917, which employment was terminated by a commission in the Chemical Warfare Service, United States Army, in 1918. His original work in metals began with the General Electric Company at Cleveland in 1919, where he was a pioneer in the use of X-rays for studying the crystal structure of steel. At the Atlas Steel Corporation (now Allegheny-Ludlum) he continued his intensive study of alloy steel (1922), and also at the Union Carbide and Carbon Research Laboratories from 1924 to 1928. In 1928, Dr. Bain became a member of the department of Research and Technology, United States Steel Corporation, being appointed Assistant to the Vice-President in 1935. In March, 1943, he was appointed Vice-President in Charge of Research and Technology, Carnegie-Illinois Steel Corporation (now United States Steel Corporation).

Dr. Bain is a member of the Sigma Xi and Phi Lambda Upsilon honorary scientific societies; he has been Trustee and President of the American Society for Metals, active in the American Institute of Mining and Metallurgical Engineers, and is now Chairman of the General Research Committee of the American Iron and Steel Institute. He is a National Councillor, formerly Trustee, of the Ohio State University Research Foundation, and is a member of the Metallurgical Visiting Committee of Massachusetts Institute of Technology. He has been awarded the Robert W. Hunt Gold Medal (1929); the Henry Marion Howe Gold Medal (1931); the American Iron and Steel Institute Medal (1934); these awards being for contributions to the technology of metals. In 1937 he was awarded the Benjamin Lamme Gold Medal for "eminence in engineering," and in 1946 he was awarded the Albert Sauveur Achievement Award for his "pioneering metallurgical achievements." The degree of Doctor of Engineering was conferred upon him by Lehigh University in 1936. He was the 1949 recipient of the John Price Wetherill Medal of the Franklin Institute, in recognition of his studies on the transformations in steel; for his general contributions to metallurgical research he was, in the same year, awarded the Gold Medal of the American Society for Metals. In May, 1952, Dr. Bain delivered the Sixth Annual Charles M. Schwab Memorial Lecture before the General Meeting of the American Iron and Steel Institute, and in October, 1952, he was the recipient of the Grand LeChatelier Medal of the Société Franaçise de Métallurgie. On April 28, 1954, Dr. Bain was appointed a member of the National Academy of Sciences. He presented the Eighth Hatfield Memorial Lecture at Sheffield in October, 1955.

He is author or co-author of some 40 technical publications and two books on alloy steels.

Dr. Edgar C. Bain
Hatfield Memorial Lecturer, 1955